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DEPARTMENT OF COMMERCE

Bureau of Industry and Security

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Publication of a Report on the Effect of Imports of Neodymium-Iron-Boron (NdFeB) Permanent Magnets on the National Security: An Investigation Conducted Under Section 232 of the Trade Expansion Act of 1962, as Amended

AGENCY: Bureau of Industry and Security, Commerce.

ACTION: Publication of a Report

SUMMARY: The Bureau of Industry and Security (BIS) in this notice is publishing a report that summarizes the findings of an investigation conducted by the U.S. Department of Commerce (the “Department”) pursuant to section 232 of the Trade Expansion Act of 1962, as amended (“section 232”), into the effect of imports of neodymium-iron-boron (NdFeB) permanent magnets on the national security of the United States. This report was completed in June 2022 and posted on the BIS website in September 2022. BIS has not published the appendices to the report in this notification of report findings, but they are available online at the BIS website, along with the rest of the report (*see* the ADDRESSES section).

DATES: The report was completed in June 2022. The report was posted on the BIS website in September 2022.

ADDRESSES: The full report, including the appendices to the report, are available online at https://bis.doc.gov/232.

FOR FURTHER INFORMATION CONTACT: For further information about this report contact Erika Maynard, Special Projects Manager, (202) 482-5572; and Leah Vidovich, Management and Program Analyst, (202) 482-1819. For more information about the Office of Technology Evaluation and the section 232 Investigations, please visit: http://www.bis.doc.gov/232.

SUPPLEMENTARY INFORMATION:

THE EFFECT OF IMPORTS OF NEODYMIUM-IRON-BORON (NDFEB) PERMANENT MAGNETS ON THE NATIONAL SECURITY

AN INVESTIGATION CONDUCTED UNDER SECTION 232 OF THE TRADE EXPANSION ACT OF 1962, AS AMENDED

U.S. DEPARTMENT OF COMMERCE
BUREAU OF INDUSTRY AND SECURITY
OFFICE OF TECHNOLOGY EVALUATION

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1. Executive Summary

This report summarizes the findings of an investigation conducted by the U.S. Department of Commerce (the "Department") pursuant to section 232 of the Trade Expansion Act of 1962, as amended, into the effect of imports of neodymium-iron-boron (NdFeB) permanent magnets on the national security of the United States.[1] Secretary of Commerce Gina Raimondo initiated the investigation on September 21, 2021, in response to a recommendation in the June 2021 White

[1] NdFeB magnets are also called NdFeB permanent magnets, neodymium-iron-boron (permanent) magnets, or neodymium (permanent) magnets. This report uses the term NdFeB magnets.

House Report "*Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth: 100 Day Reviews under Executive Order 14017.*" [2] [3]

As required by the statute, the Secretary considered all factors set forth in section 232(d). In particular, the Secretary examined the effect of imports on national security requirements, specifically:

i. domestic production needed for projected national defense requirements;

ii. the capacity of domestic industries to meet such requirements, including the commercial demand needed for economic viability;

iii. existing and anticipated availabilities of the human resources, products, raw materials, and other supplies and services essential to the national defense;

iv. the requirements of growth of such industries and such supplies and services including the investment, exploration, and development necessary to assure such growth; and

v. the importation of goods in terms of their quantities, availabilities, character, and use as those affect such industries; and the capacity of the United States to meet national security requirements.

In preparing this report, the Secretary also recognized the close relationship between the economic welfare of the United States and its national security. Factors that can compromise the nation's economic welfare include, but are not limited to, the impact of "foreign competition on the economic welfare of individual domestic industries; and any substantial unemployment, decrease in revenues of government, loss of skills, or any other serious effects resulting from the displacement of any domestic products by excessive imports." *See* 19 U.S.C. 1862(d). In particular, this report assesses whether NdFeB magnets are being imported "in such quantities" and "under such circumstances" as to "threaten to impair the national security."[4]

The investigation was initiated to evaluate the effects of imports of NdFeB magnets on the national security. There are two types of NdFeB magnets – sintered and bonded. However, the investigation and this report largely focus on sintered NdFeB magnets because: 1) Sintered NdFeB magnets comprise over 93 percent of the global NdFeB magnet market and are forecast to grow to over 97 percent of the global market by 2030; 2) Sintered NdFeB magnets have a greater maximum energy product than bonded NdFeB magnets, making them essential in high-

[2] Section 4 of this Report, "Product Scope of the Investigation," discusses the products under investigation. Section 4 also details ancillary products the Department examined to provide traction on the investigation.
[3] *See* "Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth: 100 Day Reviews Under Executive Order 14017," The White House, June 2021, https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf.
[4] 19 U.S.C. 1862(b)(3)(A).

temperature applications required by the defense and critical infrastructure sectors; and 3) Sintered NdFeB magnets are less easily substituted for than their bonded counterparts.[5] [6]

NdFeB magnets are the strongest permanent magnets commercially available and improve the efficiency of electrical machines. NdFeB magnets are used in hundreds of products ranging from the ubiquitous, such as headphones and air conditioners, to the highly specialized, like industrial robots. Of particular importance for evaluating the effects of imports of NdFeB magnets on the national security are NdFeB magnets' use in defense systems, including ship propulsion systems and guided missile actuators, as well as numerous critical infrastructure applications such as electric vehicle motors and offshore wind turbine generators.[7] Although NdFeB magnets' value tends to be small relative to the cost of the end-product, they are nonetheless key to product performance.

NdFeB magnets are composed of about 69 percent iron, 30 percent rare earths, and one percent boron by weight.[8] NdFeB magnets contain a mix of rare earth elements, primarily neodymium, praseodymium, dysprosium, and terbium, depending on the end use.[9] NdFeB magnets' iron-boron component is made up of American Iron and Steel Institute 1001 steel and ferroboron.[10] [11] Small amounts of material, such as nickel and copper, dry-sprayed epoxy, or e-coat (epoxy), are also used to coat NdFeB magnets to prevent corrosion.[12] The rare earth element component constitutes the largest portion of NdFeB magnet cost.

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[5] Energy product refers to the magnetic energy stored in material, dependent on coercivity and magnetization. "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

[6] References to NdFeB magnets indicate sintered NdFeB magnets, except where otherwise specified.

[7] The Presidential Policy Directive on Critical Infrastructure Security and Resilience (PPD-21) advances a national policy to strengthen and maintain secure, functioning, and resilient critical infrastructure. The Cybersecurity and Infrastructure Security Agency maintains a list of 16 critical infrastructure sectors "whose assets, systems, and networks, whether physical or virtual, are considered so vital to the United States that their incapacitation or destruction would have a debilitating effect on security, national economic security, national public health or safety, or any combination thereof." Most relevant to NdFeB magnet applications are the Critical Manufacturing, Defense Industrial Base, and Energy sectors, although NdFeB magnets are used widely in other critical infrastructure sectors, including the Healthcare and Public Health and the Information Technology sectors. *See* "Critical Infrastructure Sectors," Cybersecurity and Infrastructure Security Agency, October 21, 2020, https://www.cisa.gov/critical-infrastructure-sectors.

[8] "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.usitc.gov/publications/332/working_papers/rare_earths_and_the_electronics_sector_final_070921_2-compliant.pdf.

[9] Toyota announced in 2018 that it had developed a NdFeB magnet that substituted cerium and lanthanum for neodymium, lowering total neodymium use by 50 percent. Although cerium substitution typically leads to reduced performance in the form of lower heat resistance and coercivity, Toyota claimed to have discovered a ratio at which deterioration is suppressed. At the time of the announcement, Toyota expected the magnets would be used in the first half of the 2020s, but more recent updates are not available. *See* "Toyota Develops New Magnet for Electric Motors Aiming to Reduce Use of Critical Rare-Earth Element by up to 50%," Toyota, February 20, 2018, https://global.toyota/en/newsroom/corporate/21139684.html.

[10] The American Iron and Steel Institute and the Society of Automotive Engineers assign designations to types of steel. 1001 steel refers to a type of carbon steel. *See* "Introduction to the SAE/AISI Steel Numbering System," The Process Piping, n.d., https://www.theprocesspiping.com/introduction-sae-aisi-steel-numbering-system/.

[11] "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.usitc.gov/publications/332/working_papers/rare_earths_and_the_electronics_sector_final_070921_2-compliant.pdf.

[12] Ibid.

There are five main value chain steps prior to the production of NdFeB magnets: mixed rare earth element mining, processing of rare earth elements into rare earth carbonates, separation of rare earth carbonates into individual rare earth oxides, reduction of rare earth oxides into metals, and alloying of rare earth metals.[13] [14] Magnet manufacturers then process rare earth alloys into either sintered or bonded NdFeB magnets. Sintered magnets are produced by compacting powdered alloy into a solid mass by vacuum pressure without melting it to the point of liquefaction. Bonded magnets are made of rapidly quenched NdFeB magnetic powder mixed into binder and shaped through compression, injection molding, or calendaring.

Except for rare earths mining, the United States is not presently a major participant in the NdFeB magnet value chain. The United States has extremely limited capacity to manufacture NdFeB magnets and is nearly one hundred percent dependent on imports to meet commercial and defense requirements. In 2021, the United States imported 75 percent of its sintered NdFeB magnet supply from China, with nine percent, five percent, and four percent coming from Japan, the Philippines, and Germany, respectively.[15] [16] [17] There is currently only one firm in the United States, Noveon (formerly Urban Mining Company), that produces sintered NdFeB magnets, albeit in small quantities.[18] [19] [20] The United States has no domestic production of rare earth oxides or metal. The United States is dependent on foreign sources, especially China, for NdFeB magnets.

China dominates all steps of the global NdFeB magnet value chain.[21] In 2020, China controlled about 92 percent of the global NdFeB magnet and magnet alloy market.[22] China also dominated the 2020 upstream value chain steps, controlling about 58 percent of the rare earth mining market, 89 percent of the oxide separation market, and 90 percent of the metallization market.[23]

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[13] Rare earth carbonates are also referred to as mixed intermediates, although the term mixed intermediates can cover rare earth chlorides.

[14] Some publications condense processing and separation or metallization and alloying into single value chain steps, for a total of three or four value chain steps prior to magnet production. The Department elected to divide the value chain into five steps prior to magnet production based on industry consultation.

[15] The import figures cited here corresponds to the value of magnet imports. Using data on unit imports of magnets increases China's import share to almost 85 percent.

[16] The Department's calculations using USITC data. "USITC Dataweb," U.S. International Trade Commission, last modified October 25, 2021, https://dataweb.usitc.gov/trade/search/Import/HTS.

[17] Imports from the Philippines reflect activity by Japanese firms. *See* Appendix E, "Global NdFeB Magnet Production: A Firm-Level Perspective," for more information.

[18] Noveon indicated it can produce NdFeB magnets from recycled or new or "virgin" material. Meeting between Noveon and the Department of Commerce, (Virtual Meeting, November 12, 2021).

[19] There are three firms, Bunting Magnetics, the Electrodyne Company, and Tengam Engineering, that produce bonded NdFeB magnets in the United States. Meeting between the Defense Logistics Agency and the Department of Commerce, (Virtual Meeting, November 23, 2021).

[20] Noveon was called Urban Mining Company until May 2022. *See* "Urban Mining Company is now Noveon Magnetics: The Nation's Only Manufacturer of Sustainable Rare Earth Magnets Powering our Electrified Future," NewsDirect, May 16, 2022, https://newsdirect.com/news/urban-mining-company-is-now-noveon-magnetics-the-nations-only-manufacturer-of-sustainable-rare-earth-magnets-powering-our-electrified-future-214013391.

[21] *See* Section 7, "Global NdFeB Magnet Industry," and especially Appendix E, "Global NdFeB Magnet Production: A Firm-level Perspective," for more information on global NdFeB magnet value chains.

[22] "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.usitc.gov/publications/332/working_papers/rare_earths_and_the_electronics_sector_final_070921_2-compliant.pdf.

[23] China produced about 60 percent of global rare earths in 2021. Daniel Cordier, "Mineral Commodity Summaries 2022: Rare Earths," U.S. Geological Survey, January 31, 2022, https://pubs.usgs.gov/periodicals/mcs2022/mcs2022.pdf.

[24] [25] China controls an even higher percentage of the heavy rare earth mining market, including dysprosium and terbium, which are critical for high performance NdFeB magnets.[26] [27] China's dominant position in the global NdFeB magnet value chain enables it to set prices at levels that can make production unsustainable for firms operating in market economies.[28]

China is the only country with operations in all steps of the NdFeB magnet value chain, including upstream (mining, carbonates production, and separation to oxides) and downstream (metal refining, alloy production, and final magnet production) markets. All other countries maintain operations in only some steps of the upstream or downstream magnet value chain. Firms in the European Union, and especially Japan, specialize in the production of NdFeB magnets and alloys, but have no mining capacity. Japan is the second largest producer of NdFeB magnets after China, comprising about seven percent of the global market. Japanese firms also maintain magnet, alloy, and metal capacity in other countries. Firms in Germany, Finland, the Netherlands, and Slovenia produce minimal amounts of NdFeB magnets (less than one percent of global production).[29] [30] Japanese and European firms are almost completely reliant on imported feedstocks to produce metals, alloys, and ultimately NdFeB magnets.[31]

The top upstream producers of rare earth minerals in 2021 were China (60 percent), the United States (15 percent), Burma, (nine percent), and Australia (eight percent).[32] Malaysia comprises seven percent of the 2020 market for rare earth oxide separation, due entirely to the Australian firm Lynas Rare Earths.[33] Outside of China, production of metals is fragmented between Estonia, Laos, Thailand, the United Kingdom, Vietnam, and other countries, with no country having more than three percent of the market.[34]

The NdFeB magnet value chain's fragmentation means that even countries which produce NdFeB magnets remain dependent in part on Chinese inputs. Japan began diversifying its sources of rare earth elements, carbonates, and oxides away from China in the early 2010s, and

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[24] China's share of global rare earths mining increased from 58 percent in 2020 to 60 percent in 2021. *See* Section 7.1, "Global Demand."
[25] "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.usitc.gov/publications/332/working_papers/rare_earths_and_the_electronics_sector_final_070921_2-compliant.pdf.
[26] "Hyperion Testwork Confirms High Value Heavy Rare Earths," Mining Stock Education, August 9, 2021, https://www.miningstockeducation.com/2021/08/hyperion-testwork-confirms-high-value-heavy-rare-earths/.
[27] USA Rare Earth indicated that China produces one hundred percent of the global supply of dysprosium. Meeting between USA Rare Earth and the Department of Commerce, (Virtual Meeting, December 10, 2021).
[28] For example, Molycorp, a U.S. mining firm that operated the Mountain Pass Mine in California, declared bankruptcy after China increased its export quotas and rare earth prices fell. Tom Hals, "Creditors of bankrupt rare earths miner Molycorp reach deal," Reuters, February 23, 2016, https://www.reuters.com/article/molycorp-bankruptcy-idUSL2N1621G0.
[29] "About Magnet e Motion," Magnet e Motion, n.d., https://magnetemotion.com/about-magnet-e-motion.html.
[30] "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.
[31] Neo Performance Materials produces rare earth oxides in Estonia from non-European Union feedstock. Meeting between Neo Performance Materials and the Department of Commerce, the Department of Defense, and the U.S. Geological Survey, (Virtual Meeting, November 30, 2021).
[32] Daniel Cordier, "Rare Earths: Mineral Commodity Summaries 2022," U.S. Geological Survey, 2022, https://pubs.usgs.gov/periodicals/mcs2022/mcs2022.pdf.
[33] "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.
[34] Ibid.

the European Union has ongoing initiatives to develop a resilient non-Chinese NdFeB magnet supply chain. Despite these efforts, both economies and the United States remain reliant, to differing degrees, on Chinese inputs. China has previously appeared to leverage its market dominance to achieve foreign policy outcomes. For example, in 2010 China restricted exports of rare earth elements to Japan for two months after a collision between a Chinese fishing boat and the Japanese coast guard in disputed waters.[35] [36] Dependence on China leaves U.S. firms and U.S. allies vulnerable to similar Chinese coercion that could have a negative impact on national defense and the preservation of domestic critical infrastructure, such as transportation and energy.

Ongoing efforts by the U.S. Government and the private sector are intended to mitigate this reliance on Chinese inputs and to establish U.S. production capacity at all steps of the NdFeB magnet value chain. The Department of Defense and the Department of Energy have made limited investments in organizations with the goal of reestablishing domestic production capacity throughout the supply chain. Noveon plans to expand production over the next four years. In addition, three U.S.-headquartered firms – MP Materials, Quadrant Magnetics, and USA Rare Earth – and the German company Vacuumschmelze plan to establish U.S. NdFeB magnet manufacturing facilities by 2026.[37] Noveon and MP Materials have received Department of Defense funding. MP Materials and USA Rare Earth are also looking to develop U.S. capacity in pre-magnet value chain steps, including rare earths mining, rare earth carbonates processing, rare earth oxides separation, metallization, and alloying. Other non-magnet makers are considering building U.S. facilities to produce rare earth oxides and metals. These efforts, if successful, have the potential to create a complete supply chain to produce NdFeB magnets in the United States. Based on forecasted NdFeB magnet production, domestic sources could potentially satisfy up to 51 percent of total U.S. demand by 2026.[38]

If successful, these efforts to produce NdFeB magnets in the United States will be more than sufficient to satisfy U.S. defense-related demand. However, given the fact that defense demand

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[35] "China resumes rare earth exports to Japan," BBC, November 24, 2010, https://www.bbc.com/news/business-11826870.

[36] More broadly, China has encouraged localized production and technology transfer in return for a steady supply of rare earths. *See* Wayne M. Morrison and Rachel Tang, "China's Rare Earth Industry and Export Regime: Economic and Trade Implications for the United States," Congressional Research Service, April 30, 2012, https://sgp.fas.org/crs/row/R42510.pdf.

[37] On MP Materials, *see* "MP Materials to Build U.S. Magnet Factory, Enters Long-Term Supply Agreemenwt with General Motors," MP Materials, December 9, 2021, https://mpmaterials.com/articles/mp-materials-to-build-us-magnet-factory-enters-long-term-supply-agreement-with-general-motors/; On Quadrant Magnetics, *see* "Quadrant's NeoGrass to Become New Magnet Plant in US," Magnetics Business and Technology, April 5, 2022, https://magneticsmag.com/quadrants-neograss-to-become-new-magnet-plant-in-us/; On USA Rare Earth, *see* Trish Saywell, "USA Rare Earth outlines mine-to-magnet strategy," Mining.com, January 8, 2021, https://www.mining.com/usa-rare-earth-outlines-mine-to-magnet-strategy/; On Vacuumschmelze, *see* "General Motors and Vacuumschmelze (VAC) Announce Plans to Build a New Magnet Factory in the U.S. to Support EV Growth," General Motors, December 9, 2021, https://investor.gm.com/news-releases/news-release-details/general-motors-and-vacuumschmelze-vac-announce-plans-build-new.

[38] This is a very optimistic figure with several strong assumptions and should be taken as the maximum potential contribution of the U.S. NdFeB magnet industry. The Department used data from its survey of the U.S. NdFeB magnet industry to forecast U.S. NdFeB magnet production through 2026. This does not consider domestic production of NdFeB magnet inputs such as alloy or metal, which may constrain the ability of U.S.-based firms to use domestic feedstock to produce NdFeB magnets. [TEXT REDACTED], the demand estimate includes NdFeB magnets that are and may continue to be incorporated into intermediate and final products overseas. The 2030 total demand estimate is a high-growth scenario. *See* Section 8.1.4, "Estimated NdFeB Magnet Import Penetration, 2017 to 2026," for more details.

accounts for only a small percentage of total demand, domestic firms in the NdFeB magnet value chain cannot rely solely on defense-related contracts to be viable. The nascent U.S. NdFeB magnet value chain will require substantial and consistent commercial demand and need a broad customer base to be economically sustainable. While domestic production is expected to be substantially less than total U.S. demand, direct U.S. demand for NdFeB magnets will be less than total demand because many NdFeB magnets are integrated into intermediate and final products overseas. These products – and the embedded magnets – are then imported into the United States. In addition, firms that integrate NdFeB magnets in the U.S. may be unwilling to pay a premium for domestic magnets, which are expected to cost more than their Chinese counterparts.

On a potentially positive note, global and domestic demand for NdFeB magnets is forecast to increase dramatically by 2030 and even more so by 2050. The increase in demand is largely driven by global efforts to reduce greenhouse gas emissions which boost the electric vehicle and wind turbine industries. Substantial demand growth may result in a supply crunch for NdFeB magnets but also represents a critical opportunity to establish and maintain a resilient and economically viable domestic NdFeB magnet supply chain.

1.1 Findings

In conducting the investigation, the Secretary came to the following key findings:

1. **NdFeB magnets are essential to U.S. national security**:

    a. NdFeB magnets are required for national defense systems. NdFeB magnets are currently irreplaceable in key defense applications such as fighter aircraft and missile guidance systems.

    b. NdFeB magnets are required for critical infrastructure. NdFeB magnets are used in critical infrastructure sectors including but not limited to the energy sector (e.g., offshore wind turbines), the healthcare and public health sector (e.g., some open MRI machines and other medical equipment), and the critical manufacturing sector (e.g., electric vehicle motors).

    c. NdFeB magnets are required for infrastructure that is critical for climate change mitigation, identified by the President as an essential element of U.S. national security, and the transition to a green economy.[39] In particular, NdFeB magnets are the technology of choice for electric vehicles and offshore wind turbines.

2. **Total domestic demand for NdFeB magnets is expected to grow**:

    a. Total U.S. consumption of NdFeB magnets is forecast to more than double from 2020 to 2030, driven by increased demand from the electric vehicle and wind energy industries.

[39] *See* "Executive Order on Tackling the Climate Crisis at Home and Abroad," The White House, January 27, 2021, https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/.

b. Total domestic demand growth provides an opportunity to develop the U.S. NdFeB magnet industry if enough end-user applications are manufactured in the United States and the price differential between U.S. and Chinese magnets is narrowed.

3. **The United States and its allies are dependent on imports from China**:

   a. The United States is essentially one hundred percent dependent on imports of sintered NdFeB magnets and is highly dependent on imports of bonded NdFeB magnets, primarily from China. The United States also lacks domestic capacity at various earlier steps in the NdFeB magnet value chain.

   b. U.S. allies are also dependent on Chinese production, which provides China political leverage.

4. **The United States will continue to depend on imports:**

   a. There are multiple firms that intend to establish domestic capacity at different steps of the NdFeB magnet value chain. Although these plans have the potential to create a U.S. NdFeB magnet value chain from mine to magnet, they will not produce enough magnets to eliminate U.S. dependence on Chinese imports.

   b. Domestic NdFeB magnet manufacturing will be constrained by capacity limitations at earlier steps in the value chain, in particular rare earth metal refining and NdFeB alloy production. Some U.S. NdFeB magnet manufacturers will have to rely on imported metal and alloy feedstocks to produce NdFeB magnets.

   c. The U.S. NdFeB magnet industry will struggle to fulfill total critical infrastructure demand.

5. **The U.S. NdFeB magnet industry faces significant challenges**:

   a. The nascent U.S. NdFeB magnet industry faces significant barriers to reaching its production targets. These include but are not limited to Chinese competition, financial and human capital constraints, and consistent demand for more expensive domestic magnets.

1.2 Determination

Based on the findings in this report, the Secretary concludes that the present quantities and circumstances of NdFeB magnet imports threaten to impair the national security as defined in section 232 of Trade Expansion Act of 1962, as amended.

1.3 Recommendations

The Department has identified several non-exhaustive actions that would facilitate the development of a domestic NdFeB magnet industry, support a reliable supply of NdFeB magnets, and lessen the risk that NdFeB magnet imports threaten the national security. The Secretary recommends pursuing all proposed actions.

1. The U.S. Government should engage with allies through existing fora to efficiently develop production from diverse sources, promote research on NdFeB magnet-related technologies, encourage intellectual property licensing, and cooperate on foreign investment review mechanisms.

2. To bolster the U.S. NdFeB magnet industry by targeting domestic supply the U.S. Government should:

   a. Establish a tax credit for domestic manufacturing of rare earth elements, NdFeB magnets, and NdFeB magnet substitutes.

   b. Continue to direct Defense Production Act (DPA) Title III funding to firms in the U.S. NdFeB magnet industry, in particular to establish metal refining and alloy production facilities.

   c. Encourage eligible NdFeB magnet industry participants to use Export-Import Bank financing through the Make More in America Initiative and the China and Transformational Exports Program.

   d. Allocate additional funding to NdFeB magnet industry participants through other applicable instruments, such as the Bipartisan Infrastructure Law.

   e. Use the Defense Priorities and Allocations System to facilitate NdFeB magnet industry participants' acquisition of critical equipment and feedstock.

   f. Evaluate the use of export controls for domestic producers who face difficulties acquiring feedstocks from domestic sources due to competition with foreign consumers.

   g. Increase the National Defense Stockpile inventories of rare earth elements and other strategic and critical materials related to NdFeB magnets.

3. To promote the development of a domestic industry by enhancing domestic demand the U.S. Government should:

   a. Establish a forum under a lead U.S. Government agency to facilitate cooperation and share information about industry-wide issues between producers and consumers of NdFeB magnets, alloys, rare earth metals, and rare earth oxides. In particular, the U.S. Government should use DPA Title VII to promote offtake agreements using voluntary agreements.

b. Promote the recycling and reprocessing of NdFeB magnets by developing labeling requirements for end-of-life products using NdFeB magnets, leveraging the Defense Logistics Agency's Strategic Material Recovery and Reuse Program, U.S. Government-owned data centers, and other U.S. Government-owned products like electric vehicles to establish a source of recyclable feedstock, and exploring reuse of other potential feedstocks such as heavy mineral sands and coal tailings.

c. Mandate minimum domestic and ally content requirements for NdFeB magnets used in U.S. Government-owned electric vehicles and offshore wind turbines that power U.S. Government-owned buildings. NdFeB magnets used in these products should be produced domestically or by allies and contain feedstock sourced domestically or from allies. To minimize disruption, content requirements can be phased-in and waived if there are insufficient eligible sources.

d. Establish a consumer rebate for products, such as electric vehicles, that use U.S. or ally produced NdFeB magnets.

4. To support the medium- to long-term development of the U.S. NdFeB magnet industry and enhance the resiliency of the U.S. NdFeB magnet supply chain, the U.S. Government should:

   a. Continue to fund research to reduce the use of rare earth elements in NdFeB magnets, develop magnets that can substitute for NdFeB magnets, and develop technologies that avoid the use of magnets – including NdFeB magnets – in electric vehicle motors and wind turbine generators.

   b. Support the development of the human capital required by the nascent NdFeB magnet industry, including materials scientists and production line workers, through applicable funding sources.

5. The U.S. Government should continue to monitor the NdFeB magnet value chain to ensure that U.S. and ally firms are not adversely impacted by non-market factors or unfair trade actions, such as intellectual property violations or dumping.

2. Legal Framework

2.1 Section 232 Requirements

Section 232 of the Trade Expansion Act of 1962, as amended, provides the Secretary with the authority to conduct investigations to determine the effect on the national security of the United States of imports of any article. It authorizes the Secretary to conduct an investigation if requested by the head of any department or agency, upon application of an interested party, or upon their own motion. *See* 19 U.S.C. 1862(b)(1)(A).

Section 232 directs the Secretary to submit to the President a report with recommendations for "action or inaction under this section" and requires the Secretary to advise the President if any article "is being imported into the United States in such quantities or under such circumstances as to threaten to impair the national security." *See* 19 U.S.C. 1862(b)(3)(A).

Section 232(d) directs the Secretary and the President to, in light of the requirements of national security and without excluding other relevant factors, give consideration to the domestic production needed for projected national defense requirements and the capacity of the United States to meet national security requirements. *See* 19 U.S.C. 1862(d).

Section 232(d) also directs the Secretary and the President to "recognize the close relation of the economic welfare of the Nation to our national security, and …take into consideration the impact of foreign competition on the economic welfare of individual domestic industries" by examining whether any substantial unemployment, decrease in revenues of government, loss of skills or investment, or other serious effects resulting from the displacement of any domestic products by excessive imports, or other factors, results in a "weakening of our internal economy" that may impair the national security.[40] *See* 19 U.S.C. 1862(d).

Once an investigation has been initiated, section 232 mandates that the Secretary provide notice to the Secretary of Defense that such an investigation has been initiated. section 232 also requires the Secretary to do the following:

1. "Consult with the Secretary of Defense regarding the methodological and policy questions raised in [the] investigation;"

2. "Seek information and advice from, and consult with, appropriate officers of the United States;" and

3. "If it is appropriate and after reasonable notice, hold public hearings or otherwise afford interested parties an opportunity to present information and advice relevant to such investigation."[41] *See* 19 U.S.C. 1862(b)(2)(A)(i)-(iii).

As detailed in the report, all of the requirements set forth above have been satisfied.
In conducting the investigation, section 232 permits the Secretary to request that the Secretary of Defense provide an assessment of the defense requirements of the article that is the subject of the investigation. *See* 19 U.S.C. 1862(b)(2)(B).

Upon completion of a section 232 investigation, the Secretary is required to submit a report to the President no later than 270 days after the date on which the investigation was initiated. *See* 19 U.S.C. 1862(b)(3)(A). The report must:

1. Set forth "the findings of such investigation with respect to the effect of the importation of such article in such quantities or under such circumstances upon the national security;"

2. Set forth, "based on such findings, the recommendations of the Secretary for action or inaction under this section;" and

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[40] An investigation under Section 232 looks at excessive imports for their threat to the national security, rather than looking at unfair trade practices as in an antidumping investigation.

[41] Department regulations (i) set forth additional authority and specific procedures for such input from interested parties, *see* 15 CFR 705.7 and 705.8, and (ii) provide that the Secretary may vary or dispense with those procedures "in emergency situations, or when in the judgment of the Department, national security interests require it." Id., § 705.9.

3. "If the Secretary finds that such article is being imported into the United States in such quantities or under such circumstances as to threaten to impair the national security . . . so advise the President." *See* 19 U.S.C. 1862(b)(3)(A).

All unclassified and non-proprietary portions of the report submitted by the Secretary to the President must be published.

Within 90 days after receiving a report in which the Secretary finds that an article is being imported into the United States in such quantities or under such circumstances as to threaten to impair the national security, the President shall:

1. "Determine whether the President concurs with the finding of the Secretary" and

2. "If the President concurs, determine the nature and duration of the action that, in the judgment of the President, must be taken to adjust the imports of the article and its derivatives so that such imports will not threaten to impair the national security." *See* 19 U.S.C. 1862(c)(1)(A).

2.2 Discussion

Although section 232 does not specifically define "national security," both section 232, and the implementing regulations at 15 CFR part 705, contain non-exclusive lists of factors that the Secretary must consider in evaluating the effect of imports on the national security. Congress in section 232 explicitly determined that "national security" includes, but is not limited to, "national defense" requirements. *See* 19 U.S.C. 1862(d).

In a 2001 report, the Department determined that "national defense" includes both the defense of the United States directly, and the "ability to project military capabilities globally."[42] The Department also concluded in 2001 that, "in addition to the satisfaction of national defense requirements, the term "national security" can be interpreted more broadly to include the general security and welfare of certain industries, beyond those necessary to satisfy national defense requirements, which are critical to the minimum operations of the economy and government." The Department called these "critical industries."[43] Although this report applies these reasonable interpretations of "national defense" and "national security," it relies on the more recent 16 critical infrastructure sectors identified in Presidential Policy Directive 21 instead of the 28 industry sectors identified in the 2001 Report.[44] [45]

Section 232 directs the Secretary to determine whether imports of any article are being made "in such quantities" or "under such circumstances" that those imports "threaten to impair the

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[42] "The Effects of Imports of Iron Ore and Semi-Finished Steel on the National Security," Department of Commerce, Bureau of Export Administration, October 2001 ("2001 Iron and Steel Report"), at 5, https://www.bis.doc.gov/index.php/documents/steel/2224-the-effect-of-imports-of-steel-on-the-national-security-with-redactions-20180111/file.

[43] Ibid.

[44] Presidential Policy Directive 21, "Critical Infrastructure Security and Resilience," February 12, 2013 ("PPD-21").

[45] "The Effects of Imports of Iron Ore and Semi-Finished Steel on the National Security," Department of Commerce, Bureau of Export Administration, October 2001 ("2001 Iron and Steel Report"), https://www.bis.doc.gov/index.php/documents/steel/2224-the-effect-of-imports-of-steel-on-the-national-security-with-redactions-20180111/file.

national security." *See* 19 U.S.C. 1862(b)(3)(A). The statutory construction makes clear that either the quantities or the circumstances, standing alone, may be sufficient to support an affirmative finding. The two may also be considered together, particularly when the circumstances act to prolong or magnify the impact of the quantities being imported.

The statute does not define a threshold for when "such quantities" of imports are sufficient to threaten to impair the national security, nor does it define the "circumstances" that might qualify.

Similarly, the statute does not require a finding that the quantities or circumstances are impairing the national security. Instead, the threshold question under section 232 is whether the quantities or circumstances "threaten to impair the national security." *See* 19 U.S.C. 1862(b)(3)(A). This makes evident that Congress expects an affirmative finding under section 232 before an actual impairment of the national security.[46]

Section 232(d) contains a list of factors for the Secretary to consider in determining if imports "threaten to impair the national security"[47] of the United States, and this list is mirrored in the implementing regulations. *See* 19 U.S.C. 1862(d) and 15 CFR 705.4. Congress was careful to note twice in section 232(d) that the list provided, though mandatory, is not exclusive.[48] Congress' illustrative list is focused on the ability of the United States to maintain the domestic capacity to provide the articles in question as needed to maintain the national security of the United States.[49] Congress broke the list of factors into two equal parts using two separate sentences. The first sentence focuses directly on "national defense" requirements, thus making clear that "national defense" is a subset of the broader term "national security." The second sentence focuses on the broader economy and expressly directs that the Secretary and the President "shall recognize the close relation of the economic welfare of the Nation to our national security."[50] *See* 19 U.S.C. 1862(d).

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[46] The 2001 Iron and Steel Report used the phrase "fundamentally threaten to impair" when discussing how imports may threaten to impair national security. *See* 2001 Iron and Steel Report at 7 and 37. Because the term "fundamentally" is not included in the statutory text and could be perceived as establishing a higher threshold, the Secretary expressly does not use the qualifier in this report. The statutory threshold in Section 232(b)(3)(A) is unambiguously "threaten to impair" and the Secretary adopts that threshold without qualification. 19 U.S.C. 1862(b)(3)(A).

[47] 19 U.S.C. 1862(b)(3)(A).

[48] *See* 19 U.S.C. 1862(d) ("the Secretary and the President shall, in light of the requirements of national security and without excluding other relevant factors . . . " and "serious effects resulting from the displacement of any domestic products by excessive imports shall be considered, without excluding other factors . . . ").

[49] This reading is supported by Congressional findings in other statutes. *See*, e.g., 15 U.S.C. 271(a)(1) ("The future well-being of the United States economy depends on a strong manufacturing base…") and 50 U.S.C. 4502(a) ("Congress finds that – (1) the security of the United States is dependent on the ability of the domestic industrial base to supply materials and services . . . (2)(C) to provide for the protection and restoration of domestic critical infrastructure operations under emergency conditions . . . (3) . . . the national defense preparedness effort of the United States government requires – (C) the development of domestic productive capacity to meet – (ii) unique technological requirements . . . (7) much of the industrial capacity that is relied upon by the United States Government for military production and other national defense purposes is deeply and directly influenced by – (A) the overall competitiveness of the industrial economy of the United States; and (B) the ability of industries in the United States, in general, to produce internationally competitive products and operate profitably while maintaining adequate research and development to preserve competitiveness with respect to military and civilian production; and (8) the inability of industries in the United States, especially smaller subcontractors and suppliers, to provide vital parts and components and other materials would impair the ability to sustain the Armed Forces of the United States in combat for longer than a short period.").

[50] *Accord* 50 U.S.C. 4502(a).

In addition to "national defense" requirements, two of the factors listed in the second sentence of section 232(d) are particularly relevant in this investigation. Both are directed at how "such quantities" of imports threaten to impair national security *See* 19 U.S.C. 1862(b)(3)(A). In administering section 232, the Secretary and the President are required to "take into consideration the impact of foreign competition on the economic welfare of individual domestic industries" and any "serious effects resulting from the displacement of any domestic products by excessive imports" in "determining whether such weakening of our internal economy may impair the national security." *See* 19 U.S.C. 1862(d).

After careful examination of the facts in this investigation, the Secretary has determined that the present quantities and circumstance of NdFeB magnets imports threaten to impair the national security, as defined in section 232.

3. Investigative Process

3.1 Initiation of Investigation

On September 21, 2021, Secretary of Commerce Gina Raimondo initiated the investigation to determine the effects of imports of NdFeB magnets on the national security based on a recommendation in the June 2021 White House Report "*Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth: 100 Day Reviews under Executive Order 14017*" ("White House Report").[51] The White House Report noted that the United States is heavily dependent on imports of NdFeB magnets, which are important components of defense and civil industrial systems, and therefore recommended that the Department evaluate whether to initiate an investigation under section 232 of the Trade Expansion Act of 1962, as amended. Pursuant to section 232(b)(1)(b), the Department notified the U.S. Department of Defense of its intent to conduct an investigation in a letter of September 21, 2021, from Secretary Raimondo to Secretary of Defense, Lloyd Austin III (*see* Appendix A).

3.2 Public Comments

On September 27, 2021, the Department published a *Federal Register* Notice announcing the initiation of an investigation to determine the effect of imports of NdFeB magnets on the national security (*see* Appendix B).[52] The notice also announced the opening of the public comment period. In the notice, the Department invited interested parties to submit written comments, opinions, data, information, or advice relevant to the criteria listed in section 705.4 of the National Security Industrial Base Regulations (15 CFR 705.4) as they affect the requirements of national security, including the following:

(a) Quantity of the articles subject to the investigation and other circumstances related to the importation of such articles;

(b) Domestic production capacity needed for these articles to meet projected national defense requirements;

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[51] "Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth: 100 Day Reviews Under Executive Order 14017," The White House, June 2021, https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf.

[52] *See* also "Notice of Request for Public Comments on Section 232 National Security Investigation of Imports of Neodymium-Iron-Boron (NdFeB) Permanent Magnets," Federal Register, September 27, 2021, https://www.federalregister.gov/documents/2021/09/27/2021-20903/notice-of-request-for-public-comments-on-section-232-national-security-investigation-of-imports-of.

(c) The capacity of domestic industries to meet projected national defense requirements;

(d) Existing and anticipated availability of human resources, products, raw materials, production equipment, facilities, and other supplies and services essential to the national defense;

(e) Growth requirements of domestic industries needed to meet national defense requirements and the supplies and services including the investment, exploration and development necessary to assure such growth;

(f) The impact of foreign competition on the economic welfare of any domestic industry essential to our national security;

(g) The displacement of any domestic products causing substantial unemployment, decrease in the revenues of government, loss of investment or specialized skills and productive capacity, or other serious effects;

(h) Relevant factors that are causing or will cause a weakening of our national economy; and

(i) Any other relevant factors

The public comment period closed on November 12, 2021. The Department received 41 submissions. Parties who submitted comments included representatives of the domestic NdFeB magnet industry, including firms at different stages of the NdFeB magnet value chain, representatives of the foreign NdFeB magnet industry, representatives of consumers of NdFeB magnets such as the automobiles and electronics industries, representatives of the governments of Australia, Canada, the European Union, and Japan, and other concerned parties.

The Department carefully reviewed the public comments and factored all arguments and data into the investigative process. Public comments from representatives of consumers of NdFeB magnets tended to oppose the implementation of tariffs, citing the negative impact of tariffs for domestic industries that incorporate NdFeB magnets into end products. Representatives of foreign governments echoed concern for the imposition of tariffs and urged the investigation to recognize the strong ties between the United States and its allies. Representatives of the domestic NdFeB magnet industry discussed their future production plans, enumerated the difficulties firms faced in establishing a domestic value chain for the production of NdFeB magnets, and proposed recommendations to alleviate challenges. Two of the most cited challenges were Chinese competition, aided by favorable tax policies, lower environmental and labor costs, and domestic subsidies, and the difficulty of acquiring key intellectual property for sintered NdFeB magnets owned by Hitachi. A number of NdFeB magnet industry stakeholders indicated support for tax credit legislation for domestically produced NdFeB magnets. The public comments of key stakeholders are summarized in Appendix C, “Public Comment Summaries,” which also includes a link to the docket number (BIS-2021-0035) under which all public comments can be viewed in full on Regulations.gov.[53]

3.3 Information Gathering and Data Collection Activities

Due to the limited number of firms engaged in the U.S. NdFeB magnet industry, it was determined that a public hearing was not necessary to conduct a comprehensive investigation. In lieu of holding a public hearing on this investigation, the Department fielded a mandatory U.S. NdFeB Permanent Magnet Industry Survey (the "survey") (*see* Appendix D, "U.S. NdFeB Permanent Magnet Industry Survey") to participants in the U.S. NdFeB magnet industry using statutory authority pursuant to section 705 of the Defense Production Act of 1950, as amended (50 U.S.C. 4555) (DPA). The Department deployed the survey on January 31, 2022, to 60 firms that it identified as current or prospective manufacturers and/or distributors of NdFeB magnets, producers of components used in the production of NdFeB magnets, and significant consumers of NdFeB magnets in critical end-use sectors, with one or more facilities in the United States. Although participants represented all steps of the NdFeB value chain, the Department made a particular effort to identify and deploy the survey to all current or near-commercialization producers of NdFeB magnets and/or components used in the production of NdFeB magnets, and only sampled a small number of distributors and end-users. Seven NdFeB magnet value chain producers headquartered outside of the United States were invited to submit responses reflecting their foreign operations on a voluntary basis. The Department received 51 complete responses.

The survey provided a mechanism for respondents to disclose confidential and non-public information. The survey collected detailed information concerning factors such as current and planned facilities, production, capacity utilization, purchases/sales, employment, capital expenditure, critical machinery, research and development, and challenges and competition. The resulting data provided the Department with detailed industry information that was otherwise not publicly available and was needed to effectively conduct analysis for this investigation.

The Department deems the information furnished in the survey responses business confidential and will not publish or disclose it except in accordance with section 705 of the DPA, which prohibits the publication or disclosure of this information unless the President determines that the withholding of such information is contrary to the interest of the national defense. Therefore, the information submitted to the Department in response to the survey will not be shared with any non-government entity other than in aggregate form.

The Department also held 17 meetings with 19 unique U.S. NdFeB magnet industry stakeholders to gather information on firms' perspectives on the industry. Table 1 displays the firms the Department held meetings with, along with their place in the value chain and the domicile of their parent firm.

Table 1: Industry Stakeholder Meeting Participants

Firm Name	Parent Location	Current Market Segment Participation	Description of Current and Planned Market Segment Participation
American Resources	United States	N/A	Planned producer of rare earth oxides from rare earth element waste from a

[53] *See* also "86 FR 53277 NdFeB Permanent Magnets 232 investigation_published 9-27-21_comments due 11-12-21," Regulations.gov, September 27, 2021, https://www.regulations.gov/document/BIS-2021-0035-0001.

			variety of feedstocks, including battery metals and end of life products.
Arnold Magnetics	United States	N/A	Current producer of samarium-cobalt magnets that indicates it could produce NdFeB magnets if it had access to relevant intellectual property.
Energy Fuels	United States	Rare Earth Carbonates Processing	Current producer of mixed rare earth carbonates from monazite. Prospective producer of rare earth oxides and rare earth metals.
General Motors	United States	NdFeB Magnet Consumer	Current consumer of NdFeB magnets. Has a binding agreement with MP Materials and a non-binding agreement with Vacuumschmelze to purchase NdFeB magnets.
IperionX	Australia	N/A	Planned domestic producer of heavy mineral sands and monazite, which can be processed into rare earth carbonates.
Lynas Rare Earths	Australia	Rare Earth Element Mining; Rare Earth Oxide Separation	Current rare earth element miner and producer of mixed and separated rare earth oxides. Current production is outside of the United States but planned rare earth oxide production in the United States.
MP Materials	United States	Rare Earth Element Mining	Current producer of rare earth elements. Planned producer of rare earth oxides, rare earth metals, rare earth alloys, and NdFeB magnets.
National Electrical Manufacturers Association	United States	NdFeB Magnet Consumer	An industry association that includes current consumers of NdFeB magnets. Representatives of Danfoss (products include heat pumps and motors), NIDEC (products include motors), and ABB (products include robotics) participated.
Neo Performance Materials	Canada	Rare Earth Oxide Separation; Metal Refining; Rare Earth Alloy Production; NdFeB Magnet Production	Current producer of rare earth oxides, rare earth metals, rare earth alloys, and NdFeB magnets. Production is entirely outside of the United States.
Niron Magnetics	United States	N/A	Planned producer of iron-nitride magnets, a NdFeB magnet substitute.
Quadrant Magnetics	United States	N/A	Planned producer of NdFeB magnets.
Shin-Etsu	Japan	Metal Refining; Rare Earth Alloy Production; NdFeB Magnet Production	Current producer of rare earth metals, rare earth alloys, and NdFeB magnets. Production is entirely outside of the United States.

Turntide Technologies	United States	NdFeB Magnet Substitute Production	Current producer of a NdFeB magnet-free motor.
Noveon	United States	NdFeB Magnet Production; NdFeB Magnet Recycling	Current recycler and remanufacturer of NdFeB magnets. [TEXT REDACTED].
USA Rare Earth	United States	N/A	Planned rare earth element miner and planned producer of rare earth carbonates, rare earth oxides, and NdFeB magnets.
Vacuumschmelze	Germany	NdFeB Magnet Production	Current producer of NdFeB magnets. Planned NdFeB magnet production in the United States.

3.4 Interagency Consultation

The Department consulted with the Department of Defense's Office of Industrial Base Policy and the Defense Logistics Agency regarding estimates of defense-related demand, as well as methodological and policy questions that arose during the investigation. The Department also consulted with other U.S. Government agencies with expertise and information regarding the NdFeB magnet industry including the Department of Energy, the Department of State, and the Environmental Protection Agency.

4. Product Scope of the Investigation

The directive of the investigation is to assess the effects of imports of NdFeB magnets on the national security of the United States. NdFeB magnets can be produced through bonding or sintering processes. Sintered magnets currently comprise approximately 93 percent of the global NdFeB magnet market, can be used in more demanding applications, and are not easily substitutable with alternative materials.[54] [55] Harmonized Tariff Schedule (HTS) 8505.11.0070 covers the imports of "Permanent magnets and articles intended to become magnets after magnetization: Of metal: Sintered neodymium-iron-boron." Bonded NdFeB magnets do not have their own HTS code but fall under HTS 8505.11.0090 ("Permanent magnets and articles intended to become magnets after magnetization: Of metal: Other").

In order to ensure that the full NdFeB magnet value chain was covered, the Department also examined the supply chains of feedstocks and primary and intermediate products essential to the production of NdFeB magnets. These include rare earths, rare earth carbonates, rare earth oxides, rare earth metals, and rare earth alloys. NdFeB magnets generally use four rare earth elements with supply chain vulnerabilities: neodymium, praseodymium, dysprosium, and terbium.[56] Although iron in the form of 1001 steel, boron, and coating materials such as copper are also

[54] "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

[55] Meeting between the Critical Materials Institute and the Department of Commerce, (Virtual Meeting October 6, 2021).

[56] Cerium is sometimes used in NdFeB magnets but is an overproduced rare earth element and as such does not pose a supply chain vulnerability.

components of NdFeB magnets, their supply chains are not expected to pose major issues for magnet production and were not a focus of this investigation.[57]

As of 2020, consumer electronics constituted the largest source of total U.S. demand for NdFeB magnets (45 percent), followed by industrial motors (30 percent).[58] However, this investigation and report focuses on NdFeB magnets' use in electric vehicles and wind turbines, in addition to defense systems, for several reasons. The U.S. Government has recognized the electric vehicle and wind turbine industries as critical infrastructure.[59] These industries are forecast to be the main drivers of total demand growth for NdFeB magnets, reaching 55 percent of total U.S. demand by 2030 and 61 percent of total U.S. demand by 2050 (*see* section 6.2, "U.S Demand").[60] In addition, U.S. leadership in and adoption of these technologies are key to the U.S. Government's efforts to address the existential threat caused by climate change. The investigation therefore also considered industries that depend on NdFeB magnets, focusing on the electric vehicle and wind turbine industries. Understanding and considering the effects of any determinations and recommendations on these and other NdFeB magnet-consuming sectors is necessary to ensure a complete analysis of the effect of NdFeB magnet imports on the national security.

5. NdFeB Magnet Production

5.1 Production Process and Value Chain Steps

NdFeB magnets are an intermediate product composed of rare earths and other elements and are necessary for incorporation into a variety of consumer, infrastructure, and defense end-uses.[61] By weight, NdFeB magnets are typically composed of about 30 percent rare earth elements, 69 percent iron, and one percent boron. NdFeB magnets primarily use neodymium and praseodymium, with various amounts of dysprosium or terbium added to increase coercivity at elevated temperatures (i.e., heat resistance). As mentioned earlier, this investigation focuses on the rare earths value chain and current and prospective U.S. production and does not consider iron and boron. There are six main steps in the NdFeB magnet value chain inclusive of magnet production: mining, mixed rare earths processing to carbonates, separation of carbonates into oxides, refinement of oxides into metal, alloy production, and magnet production.

Rare earth elements can be extracted from mining, unconventional sources, and recycled materials. There are two groups of rare earths – light rare earths and heavy rare earths – defined by their atomic weights. In the United States, rare earths are mined from bastnaesite, a light rare

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[57] "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

[58] Ibid.

[59] *See* "Critical Infrastructure Sectors," Cybersecurity and Infrastructure Security Agency, October 21, 2020, https://www.cisa.gov/critical-infrastructure-sectors.

[60] "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf

[61] Except where otherwise noted, this section summarizes information on the NdFeB magnet value chain found in the DoE's "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report." *See* "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

earth-rich ore, or monazite, generally as a byproduct of heavy mineral sands.[62] Outside of the United States, ion adsorption clays, sometimes called ionic clays, are also a source of rare earths, especially heavy rare earths.[63] [64] Mining projects are often referred to by their grade, which indicates the percentage of rare earths contained in the mined ore. For reference, the Mountain Pass Mine in California, owned and operated by MP Materials, is considered one of the world's highest-grade deposits of bastnaesite, containing on average about seven percent rare earths content.[65] Lynas Rare Earths' Mt. Weld deposit in Western Australia, the other major non-Chinese deposit currently in operation, has a designated grade of about eight percent.[66] Once mined, rare earths are beneficiated using one of several techniques to increase the concentration of rare earths. Research has also been done on extracting rare earths from unconventional sources, such as coal ash and mine tailings, although these techniques have not been commercialized.

Once mined and concentrated, rare earths are separated into individual rare earth oxides. The primary method used to separate rare earth oxides is solvent extraction. The first step in the process is usually to remove cerium, since it is a low-value rare earth element. The cerium-free rare earth oxide mixture is then placed in mixer settlers composed of acidic reagents to separate rare earth elements based on their atomic weight. As a result, solvent extraction consumes significant quantities of acid and water and generates environmentally unfriendly waste. Solvent extraction processes are also tailored to feedstocks. Although facilities can be reorganized to accommodate new sources of rare earth concentrate, it takes time and resources to do so.[67] [TEXT REDACTED].[68] Rare earths can also be extracted from end-of-life products.

Rare earth oxides are then refined into metals, most often through electrowinning and calcium reduction.[69] Electrowinning uses a cell made of anodes and cathodes and an electrolyte, while calcium reduction relies on sodium metal to reduce anhydrous rare earth salts. Industry participants indicate that metallization is an energy intensive and potentially hazardous process.[70]

Finally, alloys are made by combining selected rare earth metals with iron and boron. There are two types of alloying approaches depending on whether they are meant to produce bonded or sintered NdFeB magnets. Although both sintered and bonded NdFeB magnets use neodymium and praseodymium, sintered NdFeB magnet alloy includes between 0.5 and 11 percent dysprosium or terbium by weight to improve high-temperature resistance to demagnetization,

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[62] Heavy mineral sands are mainly mined for titanium and zircon. *See* "Heavy Mineral Sand," Science Direct, n.d., https://www.sciencedirect.com/topics/engineering/heavy-mineral-sand.
[63] Although there may be deposits of ionic clays in the United States, they are not currently a source of rare earth elements. *See* "Rare Earth Element Accumulation Processes Resulting in High-Value Metal Enrichments in Regolith," U.S. Geological Survey, August 3, 2018, https://www.usgs.gov/centers/geology%2C-energy-%26amp%3Bamp%3B-minerals-science-center/science/rare-earth-element-accumulation#overview.
[64] Ionic clays are an important source of heavy rare earths in China. *See* Daniel J. Packey and Dudley Kingsnorth, "The impact of unregulated ionic clay rare earth mining in China," Resources Policy 48: 112-116, https://doi.org/10.1016/j.resourpol.2016.03.003.
[65] Comments of MP Materials to Request for Public Comments, "Section 232 National Security Investigation of Imports of Neodymium-Iron-Boron (NdFeB) Permanent Magnets," 86 FR 53277, November 12, 2021.
[66] "2021 Annual Report," Lynas Rare Earths, Ltd., 2021, https://wcsecure.weblink.com.au/pdf/LYC/02434182.pdf.
[67] Meeting between Lynas Rare Earths and the Department of Commerce, (Virtual Meeting, March 30, 2022); Meeting between USA Rare Earth and the Department of Commerce, (Virtual Meeting, December 10, 2021).
[68] Meeting between USA Rare Earth and the Department of Commerce, (Virtual Meeting, December 10, 2021).
[69] Thomas Lograsso, Critical Materials Institute, written communication, May 8, 2022.
[70] Meeting between Energy Fuels and the Department of Commerce, (Virtual Meeting, March 1, 2022).

while the absence of these elements in bonded magnets precludes their use in elevated temperature applications.

Sintered NdFeB magnets are manufactured using powder metallurgy. For sintered magnets, specific alloys are first produced and melted. The molten alloy is then poured on the outer surface of a rotating metal cylinder in a process known as strip casting. After strip casting, the as-cast strips are jet milled into a powder with small grains that can be used for magnet production. Jet milling shapes the grains that define the magnet microstructure and affects the magnet's performance parameters. The powder is next aligned and pressed in a magnetic field before being sintered in a high temperature furnace to form the anisotropic magnets. The magnets are then machined to specified shapes depending on their end-use and coated with a metal film to protect the magnet from corrosion. The most common coating is a nickel-copper-nickel layer, although other coatings use gold, chrome, copper, and dry-sprayed epoxy or e-coat epoxy. Finally, magnets are magnetized using a high magnetic field to align the magnetization of the grains.

Bonded NdFeB magnets follow a similar process to sintered NdFeB magnets through the production of magnetic powder. Bonded NdFeB magnets are often made from rapidly solidified material turned into ribbons through melt-spinning or jet casting, which is subsequently milled, or from spherical powders through gas or centrifugal atomization.[71] Bonded NdFeB magnets can also be made from strip cast material after hydrogen decrepitation.[72] The rapidly solidified powder feedstock is then mixed with a binder to form a final shape using compression bonding, injection molding, or calendaring.[73] In compression bonding a liquid coating of thermoset epoxy is applied to the powder, which is then added to a press cavity and compacted under heat to produce a rigid magnet.[74] Injection molding entails blending powder with a thermoplastic compound and injecting it into a mold cavity to form a rigid or flexible magnet.[75] Calendaring uses a roll press to form flexible magnet sheets.[76] Rigid magnets require binders such as nylon, Teflon, vinyl, and thermoset epoxy, while flexible magnets rely on binders like nitrile rubber and vinyl.[77]

5.2 Rare Earth Element Losses in Magnet Production

It is difficult to estimate rare earth element losses from the mining to metallization value chain steps. Rare earth recovery from ore is complex since there are a variety of different rare earth

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[71] John J. Croat, "4 – Production of rapidly solidified NdFeB magnetic powder," Rapidly Solidified Neodymium-Iron-Boron Permanent Magnets, 2018, https://doi.org/10.1016/B978-0-08-102225-2.00004-1; B.M Ma et al., "Recent development in bonded NdFeB magnets," Journal of Magnetism and Magnetic Materials 239 (1-3): 418-423, February 2002, https://doi.org/10.1016/S0304-8853(01)00609-6.
[72] John J. Croat, "Chapter 6 – Compression bonded NdFeB permanent magnets," Modern Permanent Magnets, 2022, https://doi.org/10.1016/B978-0-323-88658-1.00007-8.
[73] Steve Constantinides and John de Leon, "Permanent Magnet Materials and Current Challenges, Arnold Magnetic Technologies, n.d., http://www.arnoldmagnetics.com/wp-content/uploads/2017/10/Permanent-Magnet-Materials-and-Current-Challenges-Constantinides-and-DeLeon-PowderMet-2011-ppr.pdf; Jun Cui et al., "Manufacturing Processes for Permanent Magnets: Part II – Bonding and Emerging Methods," JOM 74: 2492-2506, June 2022, https://doi.org/10.1007/s11837-022-05188-1.
[74] Ibid.
[75] Ibid.
[76] Ibid.
[77] John Ormerod, "Bonded Magnets: A Versatile Class of Permanent Magnets," Magnetics Business and Technology, 2015, https://bunting-dubois.com/wp-content/uploads/2021/04/Magnetics-Business-Technology-Summer-2015-8-9.pdf.

minerals including bastnaesite, monazite, and ionic clays.[78] Additionally, the process of concentrating rare earth bearing ore is tailored to specific ore deposits.[79] Once the rare earth elements are concentrated, they are generally chemically leached into solution. Depending on the specific leaching technology utilized and the technological optimization of the process stream, recovery of rare earth elements in bastnaesite ranges from 85 to 90 percent, in monazite from 89 to 98 percent, and in ionic clays from 80 to 90 percent.[80] As discussed in the previous section, various approaches, including solvent extraction, are employed to separate individual rare earth elements from mixed carbonates or mixed oxides. Total recovery of rare earth elements during solvent extraction is typically 90 to 95 percent depending on the specific process and strategy utilized.[81] Individual rare earth oxides are turned into metal using electrowinning and calcium reduction.[82] [83] Although specific data on the efficiency of electrowinning of individual rare earth elements could not be identified, the electrowinning process generally exhibits a 90 to 95 percent metal recovery rate.[84]

There is more information on material losses from alloying to magnet production.[85] Metal recovery from strip casting, used to produce NdFeB alloy, is estimated at 97 percent. Hydrogen decrepitation and jet milling, which are used to make NdFeB powder, have estimated recovery rates of 99 percent. Pressing in a magnetic field, which is used to produce the sintered magnet, has a 99 percent recovery rate, while the subsequent sintering and heat-treating steps have 98 percent recovery rates. The greatest material loss occurs when machining the sintered magnet block into a usable magnet according to end-use-determined specifications. Depending on the size and complexity of the final magnet machining has a recovery rate of 60 to 90 percent. Although considerable material is lost during the magnet machining step, the resulting waste, also known as magnet swarf, is often recycled and returns to the process flow stream.[86] Indeed, some industry participants question the viability of magnet manufacturing that does not recycle swarf.[87] The final steps in NdFeB magnet manufacturing are plating for corrosion and final

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[78] On sources of rare earth elements, *see* "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.
[79] Meeting between Lynas Rare Earths and the Department of Commerce, (Virtual Meeting, March 30, 2022); Meeting between USA Rare Earth and the Department of Commerce, (Virtual Meeting, December 10, 2021).
[80] Sebastiaan Peelman et al., "Leaching of Rare Earth Elements: Past and Present," ERES2014: 1st European Rare Earth Resources Conference, September 4 to 7, 2014, http://www.eurare.org/docs/eres2014/seventhSession/SebastiaanPeelman.pdf; Sebastiaan Peelman et al., "Chapter 21: Leaching of Rare Earth Elements: Review of Past and Present Technologies," Rare Earths Industry: Technological, Economic, and Environmental Implications: 319-334, 2016, https://doi.org/10.1016/B978-0-12-802328-0.00021-8.
[81] Laura Talens Peiro and Gara Villalba Mendez, "Material and Energy Requirement for Rare Earth Production," JOM 65: 1327-1340, 2013, https://doi.org/10.1007/s11837-013-0719-8.
[82] "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.
[83] Thomas Lograsso, Critical Materials Institute, written communication, May 8, 2022.
[84] Danielle Miousse, "A New Spin on Electrowinning," PF Products Finishing, May 1, 2007, https://www.pfonline.com/articles/a-new-spin-on-electrowinning.
[85] Unless otherwise noted, this paragraph summarizes information in a Department of Energy report on the NdFeB magnet supply chain. *See* "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.
[86] Meeting between Lynas Rare Earths and the Department of Commerce, (Virtual Meeting, March 30, 2022)
[87] Ibid.

magnetization, both of which have a yield of 99 percent. As a result, total recovery from alloy to magnet production can range from about 54 to 81 percent.[88]

6. U.S. NdFeB Magnet Industry

6.1 Historical Overview

The United States is essentially one hundred percent dependent on imports of NdFeB magnets to satisfy demand. However, the United States did not always have negligible capacity in the NdFeB magnet value chain. Rare earths were first discovered at Mountain Pass in California in 1949 and extracted by the mining firm Molycorp beginning in 1951.[89] In the 1950s, research by the Ames Laboratory advanced rare earths processing technology.[90] The combination of favorable factor endowments and research and development caused the U.S. rare earths industry to flourish. By the 1980s, Mountain Pass supplied over 70 percent of the world's rare earth elements.[91] Meanwhile, commercialized processing technologies facilitated rare earth oxide production and consumption by a growing array of end-users.[92] NdFeB magnet manufacturers were one such consumer: in 1983, General Motors and Sumitomo of Japan independently announced the development of NdFeB magnets.[93] In 1986 General Motors established a subsidiary called Magnequench to commercialize production.[94] Magnequench began production of rapidly solidified powders for isotropic bonded magnets, full dense hot pressed isotropic magnets, and fully dense anisotropic magnets in 1987.[95] [96]

However, the 1980s were marked by growing foreign competition that presaged the end of the U.S. rare earths industry. By 1985 Japan had already exceeded the United States in NdFeB magnet production and by 1987 produced over half the world's magnets.[97] Starting in the second half of the 1980s, several U.S. magnet companies licensed Sumitomo patents to produce and sell sintered NdFeB magnets.[98] In the 1980s, China also began to develop its rare earth and NdFeB magnet industries. A combination of low labor costs, less stringent environmental regulations, and tax rebates and subsidies made it difficult for U.S. firms to compete.[99] In response to imports of unlicensed Chinese magnets, in 1995 U.S. magnet manufacturer Crucible Materials filed a complaint with the U.S. International Trade Commission (U.S. ITC) requesting a section 337 investigation.[100] Although the U.S. ITC found a violation and issued a cease-and-desist order to a

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[88] The Department reached this calculation using the information on material loss from alloy to magnet production discussed in earlier in the paragraph.
[89] Joanne Abel Goldman, "The U.S. Rare Earth Industry: Its Growth and Decline," Journal of Policy History 26 (2): 139-166, 2014, https://doi.org/10.1017/S0898030614000013.
[90] Ibid.
[91] Ibid.
[92] Ibid.
[93] Ibid.
[94] Jeffrey St. Clair, "The Saga of Magnequench," Counterpunch, April 7, 2006, https://www.counterpunch.org/2006/04/07/the-saga-of-magnequench/.
[95] Ibid.
[96] V. Panchanathan, "Magnequench Magnets Status Overview," Journal of Materials Engineering and Performance, 4 (4) 423-429, 1995, https://doi.org/10.1007/BF02649302.
[97] Joanne Abel Goldman, "The U.S. Rare Earth Industry: Its Growth and Decline," Journal of Policy History 26 (2): 139-166, 2014, https://doi.org/10.1017/S0898030614000013.
[98] John Ormerod, "NdFeB Magnet Patents: Updated 2021," Bunting, n.d., https://bunting-dubois.com/tech-briefs/ndfeb-magnet-patents-update-2021/.
[99] Joanne Abel Goldman, "The U.S. Rare Earth Industry: Its Growth and Decline," Journal of Policy History 26 (2): 139-166, 2014, https://doi.org/10.1017/S0898030614000013.
[100] John Ormerod, "NdFeB Magnet Patents: Updated 2021," Bunting, n.d., https://bunting-dubois.com/tech-briefs/ndfeb-magnet-patents-update-2021/; "Certain Neodymium-Iron-Boron Magnets, Magnet Alloys, and Articles

domestic respondent as well as a general exclusion order, these actions did not prevent the offshoring of domestic industry.[101] In 1998, Molycorp suspended operation at Mountain Pass Mine, ending U.S. involvement in the upstream steps of the NdFeB magnet value chain.[102] The downstream steps of the value chain followed. For example, after being sold to Chinese owners Magnequench's U.S. factories were closed and offshored starting in 1998, and it eventually ceased U.S. production in 2006.[103] Similarly, in 2005, Hitachi closed its sintered NdFeB magnet manufacturing facility in Edmore, MI, which it had previously acquired from General Electric.[104]

The U.S. NdFeB magnet value chain experienced a brief revival in the late 2000s and early 2010s, in part due to rising rare earths prices.[105] In 2008, Molycorp sought to restart production at Mountain Pass Mine.[106] When China dramatically restricted exports of rare earths in 2010 and prices increased, Molycorp appeared poised to benefit.[107] [108] In 2012 it acquired Magnequench, which at the time had NdFeB magnet powder facilities in China and Thailand, in order to create a vertically integrated mine to magnet firm.[109] [110] By 2013 it had achieved domestic production of 5,500 tons of rare earth oxides and had established a joint venture with Mitsubishi and Daido Steel to produce magnets in Japan.[111] [112] [113] However, Molycorp struggled to remain solvent and suffered from the decline in rare earths prices that occurred in part due to China's reversal of its export restrictions, ultimately declaring bankruptcy in 2015.[114] [115] The United States has in

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Containing Same: Investigation No. 337-TA-372," U.S. International Trade Commission, May 1996, https://usitc.gov/publications/337/pub2964.pdf.

[101] Ibid.

[102] Joanne Abel Goldman, "The U.S. Rare Earth Industry: Its Growth and Decline," Journal of Policy History 26 (2): 139-166, 2014, https://doi.org/10.1017/S0898030614000013.

[103] Jeffrey St. Clair, "The Saga of Magnequench," Counterpunch, April 7, 2006, https://www.counterpunch.org/2006/04/07/the-saga-of-magnequench/.

[104] Walter Benecki, "Magnetics Industry Overview," 2005, http://www.waltbenecki.com/uploads/Another_Year_of_Significant_Change_in_the_Magnetics_Industry.pdf.

[105] *See* Section 8.3.4, "Prices and Price Volatility," for more details on neodymium oxide and metal prices.

[106] Jeffrey A. Green, "The collapse of American rare earth mining – and lessons learned," Defense News, November 12, 2019, https://www.defensenews.com/opinion/commentary/2019/11/12/the-collapse-of-american-rare-earth-mining-and-lessons-learned/.

[107] China implemented export quotas starting in 2005, but dramatically decreased the export quota by almost 40 percent in 2010. China's export quotas are broadly seen as part of a strategy of economic resource nationalism, wherein economic advantage can be transferred from foreign to local firms, although some argue they reflect an effort to gain a geopolitical advantage. China itself contended quotas were meant to decrease environmental costs, but this argument was rejected by the WTO in 2014. *See* Kristen Vekasi, "Politics, markets, and rare commodities: Responses to Chinese rare earth policy," Japanese Journal of Political Science 20 (1): 2-20, 2019, https://doi.org/10.1017/S1468109918000385.

[108] Neodymium oxide prices rose by over 1,200 percent from $27.95 per kg at the end of January 2010 to a peak of $369.75 at per kg at the end of July 2011. The Department's calculations from Bloomberg data. *See* Section 8.3.4, "Prices and Price Volatility," for more details.

[109] Artem Golev et al., "Rare earths supply chains: Current status, constraints, and opportunities," Resources Policy 41: 52-59, 2014, http://dx.doi.org/10.1016/j.resourpol.2014.03.004.

[110] Magnequench was later acquired by Neo Performance Materials after Molycorp's bankruptcy.

[111] Eugene Gholz, "Rare Earth Elements and National Security," Council on Foreign Relations, October 2014, https://cdn.cfr.org/sites/default/files/pdf/2014/10/Energy%20Report_Gholz.pdf.

[112] Joseph Gambogi, "Mineral Commodity Summaries: Rare Earths," U.S. Geological Survey, January 2017, https://d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/mineral-pubs/rare-earth/mcs-2017-raree.pdf.

[113] All quantities specified as tons in this report refer to metric tons, unless otherwise noted.

[114] Tiffany Hsu, "Molycorp – sole U.S. rare earth producer – files for bankruptcy," Los Angeles Times, June 25, 2015, https://www.latimes.com/business/la-fi-molycorp-rare-earth-bankruptcy-20150625-story.html.

[115] When Molycorp declared bankruptcy in June 2015, neodymium oxide prices were down by over 88 percent to $43.00 per kg from a peak of $369.75 per kg in July 2011. The Department's calculations from Bloomberg data. *See* Section 8.3.4, "Prices and Price Volatility," for more details.

recent years been highly reliant (well above 80 percent) on imports of bonded NdFeB magnets and essentially one hundred percent dependent on imports of sintered NdFeB magnets.

6.2 U.S. Demand

As one of the strongest types of permanent magnets, NdFeB magnets, in particular sintered NdFeB magnets, are used in an extensive range of products. Example applications include actuators for machine tools, robots, and water pumps, refrigerator and air conditioner compressors, speakers in phones and laptops (as well as more advanced applications in computing and telecommunications), and traction motors in electric vehicles.

The Department of Energy's (DoE) "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report" estimates total domestic demand for selected NdFeB magnet applications in aggregate and by broad application area, as detailed in Table 2.[116] [117] It estimated total consumption at about 16,100 tons in 2020. Based on DoE estimates, total U.S. demand for NdFeB magnets for these applications is projected to increase under a high growth scenario to 37,000 tons in 2030, with the bulk of increasing demand accounted for by offshore wind turbines and electric vehicles.

Table 2: Total U.S. demand for selected NdFeB magnet applications, thousands of tons*

Application	Total demand in 2020		Projected total demand in 2030 (high growth)		Projected total demand in 2050 (high growth)	
	Amount (kt)	Share	Amount (kt)	Share	Amount (kt)	Share
Offshore wind turbines	0	0.0%	10.1	27.3%	19	27.7%
Electric vehicles	1.8	11.2%	10.2	27.6%	23.1	33.7%
Consumer electronics (hard disk drives, cell phones, loudspeakers, other)	7.2	44.7%	7.4	20.0%	11.8	17.2%
Industrial motors	4.9	30.4%	5.9	15.9%	9.5	13.8%
Non-drivetrain motors in vehicles	1.5	9.3%	2.4	6.5%	3.9	5.7%
Other sintered magnets (Power tools, electric bikes)	0.1	0.6%	0.1	0.3%	0.2	0.3%
Bonded magnets	0.6	3.7%	0.8	2.2%	1.3	1.9%
Total	16.1	100.0%	37	100.0%	68.6	100.0%

*The figures presented represent total – or the sum of direct and embedded – demand.
Source: "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

[116] The Department notes that the global NdFeB magnet supply chain is opaque and as a result valid and reliable estimates of total as well as direct and embedded demand are difficult to generate, both in aggregate and at the end-use-level. [TEXT REDACTED]. Estimates of total, direct, and embedded demand in aggregate and by end-use category should be approached with caution.

[117] The DoE report and the figures provided in this report reflect total demand, in other words the sum of direct and indirect or embedded demand, for selected NdFeB magnet applications.

Since U.S. production of NdFeB magnets is minimal almost all the United States' direct and indirect NdFeB magnet consumption is met through imports.[118] The United States directly imported about 7,500 tons of sintered NdFeB magnets in 2021.[119] However, direct imports of NdFeB magnets represent only a portion of U.S. consumption and the majority of U.S. demand is in the form of imported products with the magnets embedded in them. As the list of imported goods containing NdFeB magnets is extensive, and their magnet content (weight and type) unknown, it is difficult to precisely estimate indirect consumption by application. The Defense Logistics Agency Strategic Materials estimates 60 percent of essential civilian demand for NdFeB magnets was fulfilled through embedded imports, [TEXT REDACTED].[120] [121]

6.3 NdFeB Magnets in Defense and Critical Infrastructure Applications

Presidential Policy Directive 21 (Critical Infrastructure Security and Resilience) designates 16 critical infrastructure sectors as vital to national security, national economic security, and/or national public health and safety.[122] NdFeB magnets are used so extensively across industries that they support virtually all 16 sectors, including the critical manufacturing, defense industrial base, energy, healthcare and public health, transportation systems, and water and wastewater systems sectors. The following sections will discuss the use of NdFeB magnets in defense applications and two key critical infrastructure applications: electric vehicles and offshore wind turbines. Defense-related uses and demand are central to the investigation's directive to assess the effects of NdFeB magnet imports on national security. Electric vehicles and offshore wind turbines are important to the Biden Administration's Clean Energy Plan and efforts to combat climate change. They will also drive demand for NdFeB magnets and are key sales targets for NdFeB magnet manufacturers.

6.3.1 Defense Applications

Consistent with their broad commercial applications, NdFeB magnets are used in a variety of defense end-uses.[123] Defense usage is not limited to specific magnet characteristics such as high coercivity. Instead, each defense application requires a specially designed magnet, of varying sizes, grades, and performance characteristics. [TEXT REDACTED]. Aircraft, missiles, and munitions use small high-powered rare earth magnet actuators that control the various surfaces during operation. NdFeB magnets can also be used as fasteners. Although substitutes can be used in some applications, they are usually not as effective.[124]

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[118] U.S. imports and exports of NdFeB magnets are further discussed in Section 6.4, "U.S. Trade in NdFeB Magnets."
[119] "USITC Dataweb," U.S. International Trade Commission, last modified October 25, 2021, https://dataweb.usitc.gov/trade/search/Import/HTS.
[120] "Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth," The White House, June 2021, https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf.
[121] Meeting between the Defense Logistics Agency and the Department of Commerce (Virtual Meeting, November 23, 2021).
[122] "Critical Infrastructure Sectors," Department of Homeland Security, last modified October 21, 2020, https://www.cisa.gov/critical-infrastructure-sectors.
[123] [TEXT REDACTED]
[124] "Defense Federal Acquisition Regulation Supplement: Restriction on the Acquisition of Certain Magnets and Tungsten," Federal Register, April 30, 2019. https://www.federalregister.gov/documents/2019/04/30/2019-08485/defense-federal-acquisition-regulation-supplement-restriction-on-the-acquisition-of-certain-magnets?msclkid=9f790985ac5011eca53be28a54128eac.

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As with total domestic consumption of NdFeB magnets, a precise total for defense-related demand is not possible. [TEXT REDACTED].[126] Thus, despite their importance to national security, defense demand for NdFeB magnets is only a small portion of overall demand and insufficient to support an economically viable domestic industry.

6.3.2 U.S. Government Actions to Reduce Defense Dependencies

Given NdFeB magnets' usage in and importance to the performance of myriad military systems, and the United States' near one hundred percent reliance on imports of NdFeB magnets, the U.S. Government has taken several steps in recent years to mitigate this reliance and address potential supply disruptions. One such measure is legislation implemented through a Defense Federal Acquisition Regulation Supplement (DFARS) that restricts the use of foreign NdFeB magnets in

125 [TEXT REDACTED]

126 [TEXT REDACTED], Noveon's *Federal Register* Notice submission estimated defense-related demand at two to ten percent. Comments of Noveon to Request for Public Comments, "Section 232 National Security Investigation of Imports of Neodymium-Iron-Boron (NdFeB) Permanent Magnets," 86 FR 53277, November 12, 2021.

the military supply chain from 2019.[127] Specifically, section 871 of the National Defense Authorization Act for 2019 (Pub. L. 115-232) prohibits the acquisition of samarium-cobalt and NdFeB magnets melted or produced in North Korea, China, Russia, or Iran because these materials play an essential role in national defense. This requirement was originally codified in 10 U.S.C. 2533c but is now 10 U.S.C. 4872. There are exceptions for "some commercially available off-the-shelf magnets incorporated into end items and for electronic devices," as well as for recycled magnets where the first melt may have taken place in China but subsequent recycling and milling takes place in the United States.[128]

The Department of Defense's (DoD) Office of Industrial Base Policy has fostered domestic production capacity across the NdFeB magnet value chain from mining to magnet manufacturing through the allocation of funding under DPA Title III and the Industrial Base Analysis and Sustainment (IBAS) programs. Other important DoD funding sources for rare earth supply chain research and scale-up include the National Defense Stockpile Program, the Rapid Innovation Fund, and the Small Business Innovation Research (SBIR) program.

Upstream in the NdFeB magnet value chain, DoD has funded the development of oxide separation capacity. In February 2021, Lynas USA LLC, a subsidiary of Australian mining firm Lynas Rare Earths, received $30.4 million to establish a facility to produce light rare earth oxides, including neodymium.[129] [130] [TEXT REDACTED]. This facility is also expected to produce heavy rare earth oxides such as dysprosium.[131] [TEXT REDACTED].[132] In February 2022, DoD awarded MP Materials $35 million under the IBAS program for a heavy rare earth oxide separation facility, on top of a previous $9.6 million commitment in December 2020 to develop light rare earth oxide separation capabilities.[133] MP Materials expects to commence production by the end of 2022.[134] DoD has also provided funding for NdFeB magnet production. In July 2020, under DPA Title III, Noveon was provided $28.8 million to develop NdFeB magnet manufacturing, which will begin in 2022 and ramp up thereafter.[135] Noveon later received $0.86 million for an inventory demonstration.[136] In November 2020, DoD also provided

[127] For more information, please refer to the *Federal Register* Notice of the rule. "Defense Federal Acquisition Regulation Supplement: Restriction on the Acquisition of Certain Magnets and Tungsten," Federal Register, April 30, 2019, https://www.federalregister.gov/documents/2019/04/30/2019-08485/defense-federal-acquisition-regulation-supplement-restriction-on-the-acquisition-of-certain-magnets.
[128] Ibid.
[129] "DoD Announces Rare Earth Element Award to Strengthen Domestic Industrial Base," Department of Defense, February 1, 2021, https://www.defense.gov/News/Releases/Release/Article/2488672/dod-announces-rare-earth-element-award-to-strengthen-domestic-industrial-base/.
[130] Unless otherwise stated, all values cited in this report are U.S. dollars.
[131] "2021 Annual Report," Lynas Rare Earths, Ltd., 2021, https://wcsecure.weblink.com.au/pdf/LYC/02434182.pdf.
[132] Meeting between Lynas Rare Earths and the Department of Commerce, (Virtual Meeting, March 30, 2022).
[133] "MP Materials Awarded Department of Defense Heavy Rare Earth Processing Contract," MP Materials, February 2, 2022, https://investors.mpmaterials.com/investor-news/news-details/2022/MP-Materials-Awarded-Department-of-Defense-Heavy-Rare-Earth-Processing-Contract/default.aspx.
[134] "Form 10-K," MP Materials, February 28, 2022, https://d18rn0p25nwr6d.cloudfront.net/CIK-0001801368/77b2894e-b746-43c5-938a-a3f524823baa.pdf.
[135] "DoD Announces $77.3 Million in Defense Production Act Title III COVID-19 Actions," Department of Defense, July 24, 2020, https://www.defense.gov/News/Releases/Release/Article/2287490/dod-announces-773-million-in-defense-production-act-title-iii-covid-19-actions/.
[136] "DoD Announces Rare Earth Element Awards to Strengthen Domestic Industrial Base," Department of Defense, November 17, 2020, https://www.defense.gov/News/Releases/Release/Article/2418542/dod-announces-rare-earth-element-awards-to-strengthen-domestic-industrial-base/.

$2.3 million in DPA Title III funding to TDA Magnetics for a rare earth element supply chain study.[137]

The U.S. Government also funded projects related to the NdFeB magnet value chain through the SBIR program.[138] SBIR provides funding on a competitive basis to encourage high technology innovation by small businesses with less than 500 employees. In general, funding of up to $275,000 over a six month to one year period is granted for Phase I projects (i.e., projects at the technical assessment and feasibility stage), and up to $1.8 million over a two-year period for Phase II projects (to allow for continued research and development after a successful Phase I). Like other federal awards, SBIR contracts allocate intellectual property rights between the U.S. Government and the awardee according to a detailed regulatory regime. A typical SBIR patent rights clause generally permits the SBIR awardee to retain ownership of inventions, but grants the U.S. Government a "non-exclusive, nontransferable, irrevocable paid-up license to practice the subject invention throughout the world."[139]

In 2020 and 2021, SBIR awards directly related to neodymium were made to ten organizations – DoD units funded three of these, and DoE units funded seven. Projects included novel separation and metal reduction technologies, as well as recycling/reclaiming rare earths and magnets from end-of-life products and waste feedstocks. Additional projects focused on the development of electric motors that are free of rare earth elements or have reduced rare earth element content. If expanded to include SBIR awards related more broadly to rare earth elements, the total number of projects funded increases to 52 in 2020 and 2021 alone, and over 300 over the history of the SBIR program.

In one example, the Defense Logistics Agency – Strategic Materials is leveraging SBIR funding and Rapid Innovation Funding to accelerate the development of new rare earth processing technologies through a grant to Rare Earth Salts.[140] Rare Earth Salts will use this money to scale production of separate rare earth oxides to 20 tons of neodymium-praseodymium at its facility in Beatrice, NE. Using a unique separations process, Rare Earth Salts claims it can separate and refine all seventeen rare earth elements, providing DoD with a viable alternative to foreign sources.[141]

DoE has also provided funding related to the NdFeB magnet value chain. For example, DoE has advanced research on recovering rare earths from unconventional sources, including coal, coal byproducts, and other waste materials.[142] Through basic and applied research conducted in DoE

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[137] Ibid.

[138] Information in this paragraph is drawn from the SBIR website. *See* "SBIR," Small Business Administration, n.d., https://www.sbir.gov/?msclkid=fddb897aac5011ec87c1465b3f85f68e.

[139] "37 CFR 401.14 - Standard patent rights clauses," Cornell Law School Legal Information Institute, n.d., https://www.law.cornell.edu/cfr/text/37/401.14.

[140] "DOD Announces Rare Earth Element Awards to Strengthen Domestic Industrial Base," Department of Defense, November 17, 2020, https://www.defense.gov/News/Releases/Release/Article/2418542/dod-announces-rare-earth-element-awards-to-strengthen-domestic-industrial-base/msclkid/dod-announces-rare-earth-element-awards-to-strengthen-domestic-industrial-base/.

[141] "Defense Logistics Agency Research and Development: Small Business Innovation Programs," Defense Logistics Agency, n.d. 2022, https://www.dla.mil/Portals/104/Documents/SmallBusiness/Always%20Accountable%20Program%20Sheet_10%20NOV%202020.pdf?ver=2A6BDQejXejBr5xDhoLDyQ%3D%3D.

[142] Information in this paragraph is drawn from a DoE document describing the program. *See* "Rare Earth Elements and Critical Minerals," National Energy Technology Laboratory, February 2022, https://www.netl.doe.gov/sites/default/files/2022-02/Program-141.pdf.

labs, small businesses, and universities, DoE was able to establish pilot scale facilities capable of producing small quantities of high purity, mixed rare earth oxides. DoE expanded this program in 2020 in response to Executive Order 13817 to include upstream beneficiation yielding mixed rare earth oxides, midstream processing, separation, recovery of rare earth elements and critical minerals, and ultimately onshore downstream manufacturing that incorporates these materials into consumer and national defense products. In 2021, efforts were initiated that address the development of innovative, cost-reduced processing for the separation of mixed rare earth elements into individual, high purity oxides, and reduction of these materials to metals for use in alloy production, advanced technology development, and component manufacturing. The final goal is to produce one to three tons a day of mixed rare earth oxides and metals in prototype separation facilities by 2026.

In April 2021, DoE, through the National Energy Technology Laboratory, announced $19 million in grants to support production of rare earth elements and critical minerals vital to manufacturing batteries, magnets, and other products important to the clean energy economy.[143] The grants, of up to $1.5 million each, were allocated to 13 projects across the country to assess resources and extract and process rare earth elements and critical minerals in traditionally fossil-fuel producing communities. Not only will these initiatives help alleviate shortages in domestic supply and place the United States at the forefront of the clean energy economy, but they support regional economic growth and job creation in economically distressed communities. Many of these projects relate to reclaiming and processing rare earth elements from coal mine-derived waste.

6.3.3 NdFeB Magnets, Climate Change, and the National Security

The Department of Defense, the Department of Homeland Security, the National Security Council, and the Director of National Intelligence have identified climate change as a threat to national security. Climate-fueled events and scarce resources create instability, heightened military tensions, and financial hazards which can lead to worsening conflicts between countries.[144] Climate change and extreme weather events may also significantly increase the dislocation and migration of people.[145] Climate change is an existential crisis that poses a grave threat to the United States and the international community. To address this crisis, President Biden established a national goal to achieve net-zero carbon emissions by 2050.[146] Transitioning away from gas powered to electric vehicles is an important part of U.S. and global efforts to address climate change by slashing greenhouse gas emissions, and NdFeB magnets are key to

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[143] The information in this paragraph is drawn from a DoE press announcement. *See* "DOE Awards $19 Million for Initiatives to Produce Rare Earth Elements and Critical Minerals," Department of Energy, April 29, 2021, https://www.energy.gov/articles/doe-awards-19-million-initiatives-produce-rare-earth-elements-and-critical-minerals.

[144] Christopher Flavelle et al., "Climate Change Poses a Widening Threat to National Security," The New York Times, October 21, 2021, https://www.nytimes.com/2021/10/21/climate/climate-change-national-security.html.

[145] Renee Cho, "Climate Migration: An Impending Global Challenge," Columbia Climate School, May 13, 2021, https://news.climate.columbia.edu/2021/05/13/climate-migration-an-impending-global-challenge/; David J. Kazcan and Jennifer Orgill-Meyer, "The impact of climate change on migration: a synthesis of recent empirical insights," Climatic Change 158: 281-300, 2020, https://doi.org/10.1007/s10584-019-02560-0; "Groundswell Part 2: Acting on International Climate Migration," World Bank, September 13, 2021, https://openknowledge.worldbank.org/handle/10986/36248.

[146] *See* "Fact Sheet: President Biden Signs Executive Order Catalyzing America's Clean Energy Economy Through Federal Sustainability," The White House, December 8, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/12/08/fact-sheet-president-biden-signs-executive-order-catalyzing-americas-clean-energy-economy-through-federal-sustainability/.

electric vehicle performance. In addition, NdFeB magnets power offshore wind turbine generators, which are another key element in achieving clean energy goals.

6.3.4 Electric Vehicles

Although the United States currently lags many other countries in the percentage of vehicles sold that are electric, President Biden has set a goal that by 2030 half of all new vehicles sold will be electric.[147] This will reduce greenhouse gas emissions by more than 60 percent over 2020 levels and positions the country to be a leader in the automobile manufacturing of the future. Funds have already been dedicated to advancing the domestic electric vehicle industry and key components such as batteries.

The global transition to electric vehicles is expected to lead to a rapid increase in demand for NdFeB magnets. Although automobile manufacturers can use non-NdFeB magnet motors, up to 95 percent of electric vehicles use rare earth magnets in their traction drive motors.[148] NdFeB magnets are highly desirable in traction drive motors because they provide high energy efficiency which allows for increased driving range. Electric vehicle drive train motors typically require higher grade NdFeB magnets (using six percent or more of dysprosium) due to the high temperature environment.

In addition to traction drive motors, NdFeB magnets, often of lesser grades, are used in various other automotive systems in both electric and conventional vehicles, including motors for door locks, mirrors, seat positioning, power steering, alternators, suspension control, anti-lock brakes, water pumps, and loudspeakers. Most sources estimate that electric vehicle drive trains use between one and two kilograms (kgs) of NdFeB magnets, with other applications using smaller amounts of NdFeB magnets.[149] [150] NdFeB magnets are a small percentage of the cost of production. The European Raw Materials Alliance (ERMA) forecasts that rare earth magnets used in electric vehicles will account for $2.3 to $3.5 billion out of a global electric vehicle market of $725 to $1,160 billion, or less than 0.5 percent of the value of the market.[151] NdFeB magnets are nonetheless key to enhancing vehicle performance over non-magnet alternatives.

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[147] *See* "Executive Order on Strengthening American Leadership in Clean Cars and Trucks," The White House, August 5, 2021, https://www.whitehouse.gov/briefing-room/presidential-actions/2021/08/05/executive-order-on-strengthening-american-leadership-in-clean-cars-and-trucks/; "Fact Sheet: President Biden Announces Steps to Drive American Leadership Forward on Clean Cars and Trucks," The White House, August 5, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/08/05/fact-sheet-president-biden-announces-steps-to-drive-american-leadership-forward-on-clean-cars-and-trucks/.

[148] Roland Gaus et al., "Rare Earth Magnets and Motors: A European Call for Action," European Raw Materials Alliance, September 2021, https://erma.eu/app/uploads/2021/09/01227816.pdf.

[149] Roland Gaus et al., "Rare Earth Magnets and Motors: A European Call for Action," European Raw Materials Alliance, September 2021, https://erma.eu/app/uploads/2021/09/01227816.pdf; "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf; Steve Constantinides, "The Big Picture: Putting the Magnet Market Trends Together," Presentation at Magnetics 2018 at Orlando, FL, February 8, 2018.

[150] Conventional vehicles also use small amounts of NdFeB magnets. Estimates of total NdFeB magnet rare earths content ranges from 4 grams to 356 grams per vehicle. *See* Ruby T. Nguyen et al., "NdFeB content in ancillary motors of U.S. conventional passenger cars and light trucks: Results from the field," Waste Management 83: 209-217, 2019, https://doi.org/10.1016/j.wasman.2018.11.017.

[151] The original figures were quoted in euros: two to three billion euros for the value of rare earth magnets used in electric vehicles and 625 to 1000 billion euros for the value of the global electric vehicle market. These figures were converted into dollars at an exchange rate of 1.16 euro to the dollar, at the lower end of the exchange rate in September 2021 when the ERMA forecast was published, which fluctuated between 1.16 and 1.19 euro to the dollar.

The developing electric vehicle industry in the United States, in addition to the global electric vehicle market, represents a valuable opportunity for current and potential NdFeB magnet manufacturers. In one extreme example, if all new vehicle sales in 2040 were electric vehicles – an estimated 125 million vehicles globally – the global electric vehicle industry alone would consume at least 156,000 tons of NdFeB magnets and 342,000 tons of total rare earth oxides.[152] By comparison, in 2020 about three million electric vehicles were sold globally (4.6 percent of total) and electric vehicles consumed 7,300 tons of NdFeB magnets.[153] [154] [155] Consumer preferences, coupled with government actions to achieve the goal of having half of vehicles sold in the United States be electric by 2030, constitute a key opportunity for the nascent U.S. NdFeB magnet industry. If enough electric vehicle drive trains are manufactured in the United States, electric vehicles are a potential source of consistent demand that could sustain a domestic NdFeB magnet industry.[156] General Motors' plan to manufacture electric vehicles in the United States and use U.S. NdFeB magnets is important step in this direction, and similar actions should be encouraged to ensure the viability of U.S. NdFeB magnet manufacturers.[157]

6.3.5 Wind Energy

Wind turbines, particularly offshore wind turbines, also represent a large growth market for NdFeB magnets. NdFeB magnets are used in wind turbines' permanent magnet synchronous generators, also referred to as direct drive generators. Although not all wind turbine systems require rare earth magnets, they are the preferred choice for offshore wind turbines due to reduced maintenance costs, generator efficiency, and generator weight (which allows for the construction of larger, higher capacity wind turbines).[158] Each wind turbine can use a ton or more

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Roland Gaus et al., "Rare Earth Magnets and Motors: A European Call for Action," European Raw Materials Alliance, September 2021, https://erma.eu/app/uploads/2021/09/01227816.pdf.

152 This figure assumes each electric vehicle consumes 1.25 kgs of NdFeB magnets. This calculation relies on electric vehicle drive trains only to calculate demand. Actual demand will be higher because of NdFeB magnet use in ancillary products, such as door locks and speakers. *See* Steve Constantinides, "The Big Picture: Putting the Magnet Market Trends Together," Presentation at Magnetics 2018 at Orlando, FL, February 8, 2018.

153 "Global EV Outlook 2021," International Energy Agency, April 2021. https://www.iea.org/reports/global-ev-outlook-2021.

154 "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

155 The differences in magnet weight per vehicle is likely attributable to the opacity of NdFeB magnet usage across the sector. The Department of Energy estimates each electric vehicle drive train uses between one and two kgs of NdFeB magnets, while Constantinides (2018) estimates each electric vehicle drive train uses 1.25 kgs of NdFeB magnets. In addition, as mentioned earlier electric vehicles also use NdFeB magnets in non-drive train applications. *See* Steve Constantinides, "The Big Picture: Putting the Magnet Market Trends Together," Presentation at Magnetics 2018 at Orlando, FL, February 8, 2018; "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

156 Indeed, electric vehicles appear to be the key market for prospective NdFeB magnet manufacturers. For example, potential market entrants cite the industry as a sales target in public documents. "Form 10-k," MP Materials, February 28, 2022, https://d18rn0p25nwr6d.cloudfront.net/CIK-0001801368/77b2894e-b746-43c5-938a-a3f524823baa.pdf.

157 "Paul A. Eisenstein," General Motors to source rare earth metals domestically for its electric vehicles," NBC, December 9, 2021, https://www.nbcnews.com/business/autos/general-motors-announces-deal-source-rare-earth-metals-electric-vehicl-rcna8265.

158 "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

of NdFeB magnets.[159] As with electric vehicles, NdFeB magnets are a negligible percentage of total wind turbine costs but are critical to performance.[160] Chinese and European firms dominate wind turbine manufacturing with 23 percent and 58 percent market share, respectively.[161] GE Renewable, the only major U.S. manufacturer, had an estimated market share of just under 12 percent in 2020.[162] However, offshore wind turbine generators that constitute the largest source of demand for NdFeB magnets are not currently produced in the United States.

At present, the United States has just seven offshore wind turbines in two operating projects.[163] The Block Island Wind Farm off the coast of Rhode Island comprises five turbines, with a generating capacity of 30 megawatts, and the Coastal Virginia Offshore Wind pilot project operates an additional two turbines, with a capacity of 12 megawatts. In contrast, Europe has 25,000 megawatts of offshore wind capacity installed. To support the President's clean energy objectives, DoE has established a goal of deploying 30 gigawatts (30,000 megawatts) of offshore wind power by 2030. To fulfill this goal, in February 2022 the U.S. Government opened bidding for offshore wind leases to developers for the New York Bight off the Atlantic coast that could generate up to seven gigawatts of energy and require 600 to 700 wind turbines. Beyond the national-level goal, eight states – Connecticut, Maryland, Massachusetts, New Jersey, New York, North Carolina, Rhode Island, and Virginia – are aiming to procure at least 39,298 megawatts of offshore wind capacity by 2040.

The goal to expand offshore wind capacity is tied to the Biden Administration's broader efforts to transition to a clean energy economy. To meet DoE's target of 30 gigawatts of offshore wind power by 2030, the industry is projected to generate over 31,000 construction period and 13,400 operating period jobs.[164] This represents a promising demand stream for emerging domestic NdFeB magnet production and may encourage further investment in domestic capacity, especially if wind turbine generators are manufactured in the United States. Already, one of the leading wind turbine manufacturers, Siemens Gamesa, announced plans to build a wind turbine blade facility in Virginia.[165] Although NdFeB magnets are primarily used in generators, this indicates some willingness on the part of the wind turbine industry to establish domestic component manufacturing. Encouraging additional domestic manufacturing of wind turbine generators would promote U.S.-based demand for NdFeB magnets and aid in the development of the U.S. NdFeB magnet industry.

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[159] Roland Gaus et al., "Rare Earth Magnets and Motors: A European Call for Action," European Raw Materials Alliance, September 2021, https://erma.eu/app/uploads/2021/09/01227816.pdf.
[160] [TEXT REDACTED].
[161] Roland Gaus et al., "Rare Earth Magnets and Motors: A European Call for Action," European Raw Materials Alliance, September 2021, https://erma.eu/app/uploads/2021/09/01227816.pdf.
[162] Shashi Barla, "Global wind turbine market: state of play," Wood Mackenzie, April 14, 2021, https://www.woodmac.com/news/opinion/global-wind-turbine-market-state-of-play/.
[163] This paragraph uses data from the Department of Energy's Offshore Wind Market Report 2021. Walter Musial et al., "Offshore Wind Market Report: 2021 Edition," Department of Energy, August 30, 2021, https://www.energy.gov/sites/default/files/2021-08/Offshore%20Wind%20Market%20Report%202021%20Edition_Final.pdf.
[164] Ibid.
[165] "Global leadership grows: Siemens Gamesa solidifies offshore presence in U.S. with Virginia blade facility," Siemens Gamesa, October 25, 2021, https://www.siemensgamesa.com/newsroom/2021/10/offshore-blade-facility-virginia-usa.

6.4 U.S. Trade in NdFeB Magnets

As noted earlier in this report, the U.S. is highly dependent on imports for nearly all its direct demand for NdFeB magnets.[166] However, using direct imports underestimates U.S. import dependence because NdFeB magnets are often embedded in imported intermediate and final goods, such as computers and headphones.

To analyze U.S. reliance on imports of NdFeB magnets, the Department examined imports of sintered NdFeB magnets (HTS 8505.11.0070) for the years 2016 to 2021 from the United States' top five import sources (as of 2021) by value, in raw numbers and by share of imports (*see* Figure 1).[167] [168] Figure 2 show the same series but using quantity (units). China is the predominant source of imports to the United States, having increased its share of magnet imports to the United States in quantity from about 70 percent in 2016 to almost 85 percent in 2021 and in value from almost 60 percent in 2016 to about 75 percent in 2021. Germany and Japan are the next largest source of imports. Japan is particularly important in terms of magnet value, representing almost nine percent of imports by value compared to under five percent of imports by quantity. This substantiates a commonly held view that Japanese magnets tend to be of higher quality or used in more specialized end products than their Chinese counterparts.[169] These data may underestimate the contribution of Japanese firms, given that exports from the Philippines and Malaysia likely reflect Japanese production facilities in these locations.[170] The share of German magnet imports to the United States has fallen substantially from about 14 percent in 2016 to under two percent in 2021 in terms of quantity and almost 11 percent in 2016 to under four percent in 2021 in terms of value.

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[166] Unless otherwise noted, all data in this section are from the U.S. International Trade Commission. *See* "USITC Dataweb," U.S. International Trade Commission, last modified October 25, 2021, https://dataweb.usitc.gov/trade/search/Import/HTS.

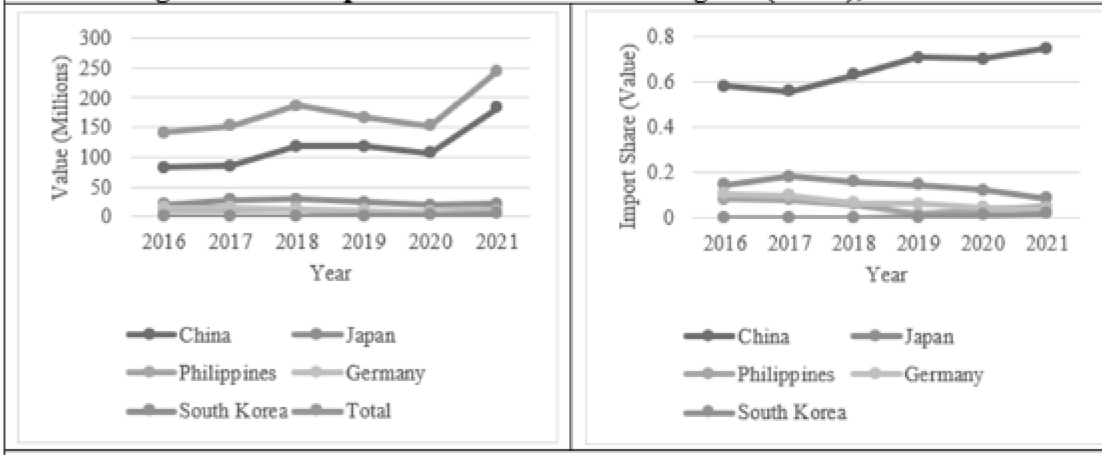
[167] Bonded NdFeB magnets do not have their own HTS code and instead fall into HTS 8505.11.0090 ("Permanent magnets and articles intended to become permanent magnets after magnetization: Of metal: Other"). Bonded NdFeB magnets comprise about seven percent of the global market, are of lower grade, and are substitutable with other magnets. Meeting between the Critical Materials Institute and the Department of Commerce, (Virtual Meeting October 6, 2021); "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf

[168] The Department also examined imports of neodymium metal (HTS 2805.30.0020). Neodymium and praseodymium metal are the only NdFeB magnet components that have their own HTS codes. Imports of neodymium metal are minimal (about $371,000 in 2021) and come almost entirely from China (about 94 percent in 2021) with the remainder imported from the United Kingdom. "USITC Dataweb," U.S. International Trade Commission, last modified October 25, 2021, https://dataweb.usitc.gov/trade/search/Import/HTS.

[169] Damien Ma and Joshua Henderson, "The Impermanence of Permanent Magnets: A Case Study on Industry, Chinese Production, and Supply Constraints," Paulson Institute, November 16, 2021. https://macropolo.org/analysis/permanent-magnets-case-study-industry-chinese-production-supply/.

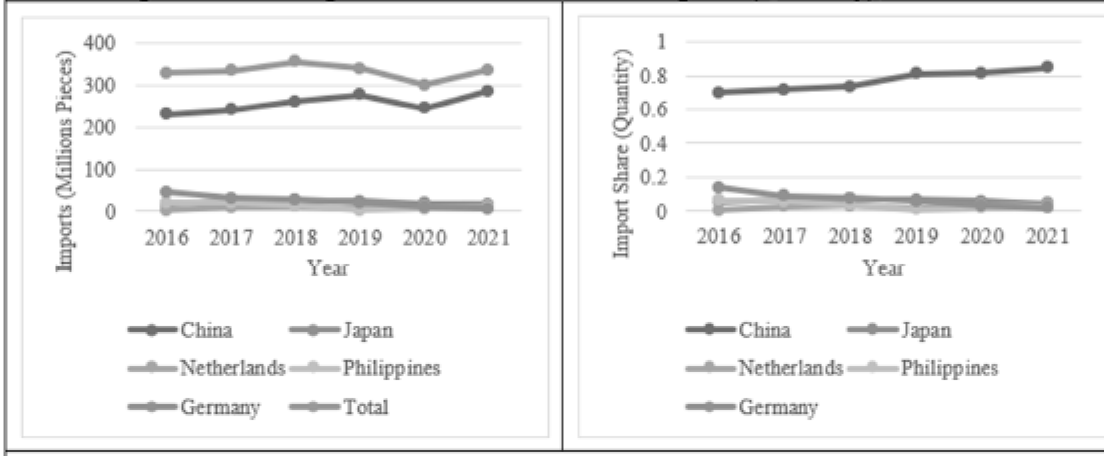
[170] "Annual Report 2021", Shin-Etsu Chemical Co., Ltd., 2021, https://www.shinetsu.co.jp/wp-content/uploads/2021/07/Annual-Report-2021-for-viewing.pdf.

Figure 1: U.S. Imports of Sintered NdFeB Magnets (Value), 2016-2021



Source: The Department's calculations, from "USITC Dataweb," U.S. International Trade Commission, last modified October 25, 2021, https://dataweb.usitc.gov/trade/search/Import/HTS.

Figure 2: U.S. Imports of Sintered NdFeB Magnets (Quantity), 2016-2021



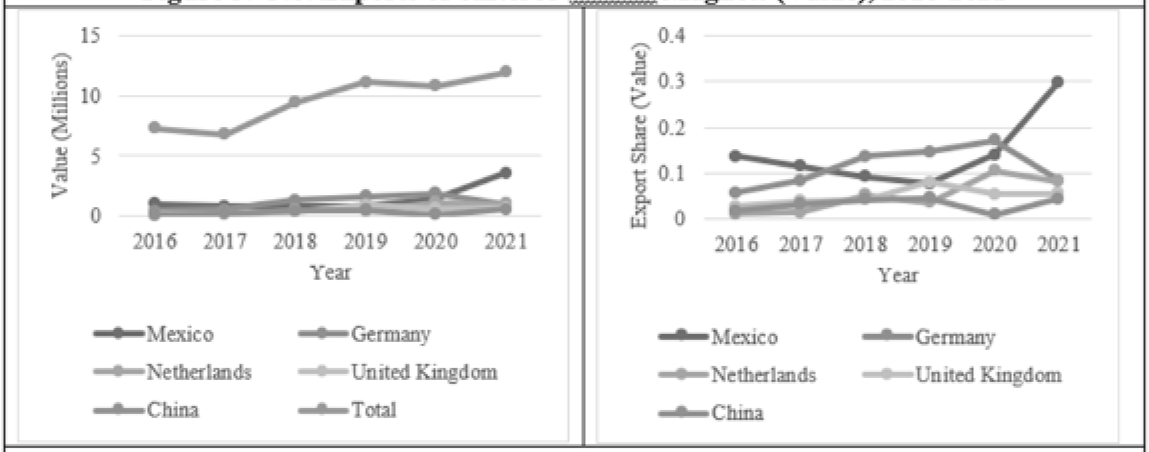
Source: The Department's calculations, from "USITC Dataweb," U.S. International Trade Commission, last modified October 25, 2021, https://dataweb.usitc.gov/trade/search/Import/HTS.

The Department also examined U.S. exports of sintered NdFeB magnets in total and to the top five destinations (as of 2021) for the same 2016 to 2021 period (*see* Figure 3).[171] Domestic exports of sintered NdFeB magnets ranged from a little over $7 million in 2016 to about $12 million in 2021. Mexico was the top destination for U.S. exports in 2021, although it still only accounted for about 30 percent of domestic sintered NdFeB magnet exports. Germany, the second most popular destination, accounted for less than nine percent of domestic sintered NdFeB magnet exports. U.S. magnet export destinations have also seen considerable turnover. In 2016, Singapore and Malaysia were the top destinations for U.S. sintered NdFeB magnet exports, accounting for about 28 percent of domestic exports ($2 million) and 15 percent of domestic exports ($1.1 million), respectively. By 2021, they were seventh at four percent ($488,000) and sixteenth at less than two percent ($185,000), respectively. Using 2021 figures,

[171] These data reflect domestic exports rather than total exports. Domestic exports measure goods that are grown, produced, or manufactured in the United States or which may have been changed, enhanced in value, or improved in condition in the United States. It therefore excludes unimproved reexports. *See* "USITC Dataweb," U.S. International Trade Commission, last modified October 25, 2021, https://dataweb.usitc.gov/trade/search/Export/HTS.

the United States imported more than 20 times the value of its domestic NdFeB magnet exports. Although there is only one active domestic producer of sintered NdFeB magnets, the United States does have an active ecosystem of magnet finishers and fabricators. These firms' activities almost certainly drive the modest value of U.S. NdFeB magnet domestic exports.

Figure 3: U.S. Exports of Sintered NdFeB Magnets (Value), 2016-2021



Source: The Department's calculations, from "USITC Dataweb," U.S. International Trade Commission, last modified October 25, 2021, https://dataweb.usitc.gov/trade/search/Export/HTS.

6.5 Duties on NdFeB Magnet Imports

NdFeB magnets and constituent products, including rare earth elements, rare earth carbonates, rare earth oxides, metals, and alloys, are subject to general tariff rates and the special tariff rate (*see* Table 5). The core product in this investigation, sintered NdFeB magnets (HTS 8505.11.0070) are subject to a general rate of 2.1 percent or a preferential rate of zero percent.[172] The overall effect of these duties on end-users is small, although not nonexistent. Some NdFeB magnet distributors/finishers/consumers note reducing tariffs on sintered NdFeB magnets would reduce their input costs, [TEXT REDACTED].[173]

Table 5: Tariff Rates for NdFeB Magnets and Magnet Components

HTS Code	Product Description	General Rate	Preferential Rate	Japan General Rate	EU General Rate[174]
8505.11.0070	Sintered NdFeB magnets	2.1 percent	Free	Free	2.2 percent
8505.11.0090	Other permanent magnets and articles intended to become permanent	2.1 percent	Free	Free	2.2 percent

[172] The general rate for all 10-digit HTS codes under HTS 8505.11.00 ("Permanent magnets and articles intended to become permanent magnets after magnetization: Of metal") is the same at 2.1 percent. Bonded NdFeB magnets, which fall under 8505.11.0090 ("Permanent magnets and articles intended to become permanent magnets after magnetization: Of metal: Other"), are therefore subject to the same rates as their sintered counterparts. The preferential tariff rate applies to qualifying imports under U.S. free trade agreements and other preference programs.

[173] U.S. Department of Commerce, Bureau of Industry and Security, NdFeB Survey.

[174] These figures reflect the stated third country duty. Autonomous tariff suspension rates may be lower – zero percent in the case of 8505.11.0070, sintered NdFeB magnets.

	magnets after magnetization of metal				
2805.30.0020	Neodymium metal	5 percent	Free	Free	2.7 to 5.5 percent[175]
2805.30.0015	Praseodymium metal	5 percent	Free	Free	2.7 to 5.5 percent
2805.30.0050	Other rare earth metals, not intermixed or interalloyed	5 percent	Free	Free	2.7 to 5.5 percent
2805.30.0090	Other rare earth metals, intermixed or interalloyed	5 percent	Free	Free	2.7 to 5.5 percent
2846.90.20	Mixtures of rare earth oxides or rare earth chlorides	Free	Free	Free	Free to 3.2 percent[176]
2846.90.80	Mixtures of rare earth carbonates other than cerium carbonate	3.7 percent	Free	Free	Free to 3.2 percent
Sources: "HTS Search," U.S. International Trade Commission, last accessed April 19, 2022, https://hts.usitc.gov/; "Access2Markets," European Commission, last accessed April 19, 2022, https://trade.ec.europa.eu/access-to-markets/en/home; "Japan's Tariff Schedule as of April 1 2022," Japan Customs, last accessed April 19, 2022, https://www.customs.go.jp/english/tariff/2022_04_01/index.htm.					

The hundreds of products containing embedded NdFeB magnets, such as electric motors, MRI machines, and consumer electronics like headphones and printers are also tracked by HTS code. Some end-use categories, including electric motors and MRI machines, are not subject to general tariff rates, while others, such as generators for wind turbines, are subject to tariffs – 2.5 percent in the case of generators.[177] As discussed earlier, the NdFeB magnet contained within final goods is generally a small percentage of the overall cost of the product.

7. Global NdFeB Magnet Industry

7.1 Global Demand

Total global demand for NdFeB magnets was estimated at about 119,000 tons in 2020, of which sintered magnets account for over 93 percent of total demand and bonded magnets the remaining

[175] Exact concordance for HTS 2805 not available.
[176] Exact concordance for HTS 2846.90 not available. The relevant products for NdFeB magnets face third country duties of 3.2 percent (neodymium and praseodymium compounds, as well as compounds of mixtures of metals) or zero percent (terbium and dysprosium compounds).
[177] "HTS Search," U.S. International Trade Commission, last accessed April 19, 2022, https://hts.usitc.gov/.

seven percent.[178] [179] As of 2020, consumer electronics and industrial motors are the primary consumers of NdFeB magnets, with about 30 percent of the market each. Offshore wind turbines account for another 14 percent of total NdFeB magnet demand, with smaller shares for electric vehicles, motors for other types of vehicles, and other applications (*see* Table 6). The magnet content in these products varies but in general accounts for a small portion of the material costs of production. Wind turbines and MRI machines use large amounts of magnets but are produced and consumed in relatively small numbers, while consumer electronic devices contain very small amounts of magnets but are produced in the millions of units. The automotive sector lies somewhere in between, with each electric vehicle drive train consuming between one and two kg of NdFeB magnets.[180] Regardless of the weight of the magnet, the strong magnetic properties provided by NdFeB magnets are key to effective and efficient product performance.

Table 6: Expected magnets contained in total global demand for selected NdFeB magnet applications, thousands of tons*

Application	**Total demand in 2020**		**Total projected demand in 2030 (high growth)**		**Total projected demand in 2050 (high growth)**	
	Amount (kt)	**Share**	**Amount (kt)**	**Share**	**Amount (kt)**	**Share**
Offshore wind turbines	16.9	14.2%	139.2	36.0%	273.7	36.3%
Electric vehicles	7.3	6.1%	114.1	29.5%	266	35.3%
Consumer electronics (hard disk drives, cell phones, loudspeakers, other)	35.1	29.4%	41	10.6%	65.4	8.7%
Industrial motors	36.0	30.2%	53.7	13.9%	85.7	11.4%
Non-drivetrain motors in vehicles	9.4	7.9%	18.3	4.7%	29.3	3.9%
Other sintered magnets (Power tools, electric bikes)	6.5	5.5%	9.6	2.5%	15.3	2.0%
Bonded magnets	8.0	6.7%	11.1	2.9%	17.7	2.3%
Total	**119.2**	**100.0%**	**387**	**100.0%**	**753.2**	**100.0%**

* The figures presented represent total – or the sum of direct and embedded – demand.
Source: "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

Total global demand for NdFeB magnets is expected to grow dramatically over the next decade, increasing from 119,000 tons in 2020 to 387,000 tons by 2030 and over 750,000 tons by 2050 in a net zero carbon emission scenario. This equates to an average annual growth rate of 12.5 percent through 2030 and 6.3 percent through 2050. Electric vehicles and offshore wind turbines

[178] Except where otherwise noted this section draws on the DoE's "Rare Earth Permanent Magnets" report. *See* "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

[179] As noted earlier, valid and reliable estimates of demand are difficult to generate because of the opacity of the global NdFeB magnet supply chain and these estimates of global demand, both in aggregate and by end-use application, should be approached with caution.

[180] "Critical Materials Strategy," Department of Energy, December 2011, https://www.energy.gov/sites/default/files/DOE_CMS2011_FINAL_Full.pdf.

will drive this growth and are projected to account for almost 30 percent and about 36 percent of NdFeB magnet demand, respectively, by 2030 as a result of the world's evolving clean energy goals. The push for energy efficiency in other sectors, including traditional NdFeB magnet applications such as consumer electronics and industrial motors, will also contribute to increased demand for NdFeB magnets. However, growth in these areas is expected to be more modest, with their share of total demand shrinking from almost 60 percent of total demand in 2020 to less than 25 percent of total demand in 2030.

The rapid growth in demand for NdFeB magnets is expected to strain the current global value chain. One market research firm forecasts that combined neodymium, praseodymium, and neodymium-praseodymium oxide shortages will rise to 21,000 tons by 2030 and 68,000 tons by 2035, while NdFeB alloy and powder shortages will reach 66,000 tons by 2030 and 206,000 tons by 2035.[181] For reference, the Department's survey of the U.S. NdFeB magnet industry indicates that by 2026 the U.S. may produce a little under [TEXT REDACTED] of rare earth oxides and about [TEXT REDACTED] of NdFeB alloys.

7.2 Global NdFeB Magnet Value Chain

The Department synthesized primary and secondary data on the global NdFeB magnet value chain's market conditions (*see* Appendix E, "Global NdFeB Magnet Production: A Firm-Level Perspective"). The Department focused on five important current and potential industry producers outside of the United States: Australia, Canada, China, the European Union, and Japan. For each country or region, participation in the main market segments (mining, processing of carbonates/separation of oxides, metallization/alloying, magnet production) plus recycling and substitution is described. The major firms involved in production, often multinationals with global operations, are also discussed.

Table 7 provides a review of market share by country for the consolidated market segments of mining, separation, metallization, and alloying/magnet manufacture. As noted earlier, China has the largest share of global production, by a large margin, at every step of the NdFeB magnet value chain. [TEXT REDACTED].[182] Australia is the third largest miner after China and the United States, and the Australian firm Lynas Rare Earths is responsible for Malaysia's seven percent share of the refined oxide market. Japan is the second largest alloy and magnet producer (seven percent in 2020), and its firms produce metals, alloys, and magnets in Japan, Southeast Asia, and China. [TEXT REDACTED].[183] The European Union has plans for significant growth in rare earth mining and magnet production, and seeks to grow its relatively small share of the oxide separation, alloying, and magnet production markets. [TEXT REDACTED].[184] Finally, Canada also plans to establish rare earth mining and separation capacity, in addition to Canadian firms such as Neo Performance Materials who maintain global capacity in multiple steps of the magnet value chain.

181 "Adamas Intelligence forecasts global demand for NdFeB magnets to increase at CAGR of 8.6% through 2035; shortages of alloys, powders, REE expected," Green Car Congress, April 20, 2022, https://www.greencarcongress.com/2022/04/20220420-adamas.html.
182 Adamas Intelligence, "Rare Earth Magnet Market Outlook to 2030," 2020.
183 Ibid.
184 Ibid.

Table 7: Market Share by Country, 2021 for Mining and 2020 for Other Steps				
Country	**Mining**[185]	**Separation**[186]	**Metal refining**[187]	**Magnet alloy manufacturing**[188]
China	60%	89%	90%	92%
U.S.	15%	-	-	<1%
Myanmar (Burma)	9%	-	-	-
Australia	8%	-	-	-
Madagascar	1%	-	-	-
India	1%	1%	-	-
Russia	1%	-	-	-
Thailand	3%	-	~3%	-[189]
Malaysia	-	7%	-	-
Estonia	-	1%	~2%	-
Japan	-	-	-	7%
Vietnam	>1%	-	~3%	1%
Laos	-	-	~2%	-
Germany	-	-	-	<1%
Slovenia	-	-	-	<1%
Finland	-	-	-	<1%
U.K.	-	-	<1%	-
Other countries	1%	2%	<1%	<1%

Source: "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf; Daniel Cordier, "Rare Earths: Mineral Commodity Summaries 2022," U.S. Geological Survey, 2022, https://pubs.usgs.gov/periodicals/mcs2022/mcs2022.pdf.

7.3 Russia and the NdFeB Magnet Industry

Russia is not a major direct participant in the NdFeB magnet value chain. In 2021 Russian production of rare earth elements was estimated at 2,700 tons, equal to about one percent of the

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185 For 2021 estimates of rare earth mine output by country, *see* Daniel Cordier, "Rare Earths: Mineral Commodity Summaries 2022," U.S. Geological Survey, 2022, https://pubs.usgs.gov/periodicals/mcs2022/mcs2022.pdf.

186 Calculated based on current understanding of where concentrate from specific producers is separated (for example, output from Lynas' Mount Weld Mine in Australia is separated at its LAMP facility in Malaysia and HREs mined in Myanmar are transported to China for further processing). "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

187 Current hypothesis based on expert consultation. "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

188 "Rare earth magnet market outlook to 2030," Adamas Intelligence, August 2020.

189 In 2019, Thailand accounted for about eight percent of bonded NdFeB powders. Neo Magnequench (a subsidiary of Neo Performance Materials) manufactures bonded magnetic powders at its facility in Korat, Thailand. "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

global market.[190] However, Russia has significant reserves of rare earths, estimated at 21 million tons or about 17.5 percent of the global total.[191] Canadian firm Neo Performance Materials states it uses Russian feedstocks in its Estonian separation facility, along with feedstocks from Australia, China, and the United States.[192] Russia does not participate in any downstream segments of the value chain.[193] In addition, the United States imports 1001 steel from Germany and sometimes Brazil, and ferroboron is produced in China, India, and Turkey.[194] Finally, based on market research and industry meetings, Russia does not appear to be a source of critical equipment for NdFeB magnet production.

[TEXT REDACTED]

One method to evaluate the exposure of the NdFeB magnet industry to Russia is to examine the effects of Russia's invasion of Ukraine on investor expectations using an event study.[195] If investors think that the NdFeB magnet industry will be negatively affected by Russia's invasion of Ukraine, an abnormal negative market return for publicly traded firms in the NdFeB magnet industry should be observed around that event. The Department therefore estimated the abnormal market return around the time of Russia's invasion of Ukraine for four NdFeB magnet industry firms: MP Materials, a rare earths miner who plans to create a vertically integrated mine to magnet firm in the United States; Energy Fuels, a U.S. rare earths processor who is considering separating oxides; Neo Performance Materials, a Canadian firm that produces rare earth oxides in Estonia, metals and alloys in Thailand and China, and NdFeB magnets in China; and Lynas Rare Earths, an Australian rare earths miner that produces oxides in Malaysia. Other public companies involved in the NdFeB magnet value chain were excluded because they are conglomerates with significant non-NdFeB magnet operations (e.g., Shin-Etsu, TDK, Hitachi), tangentially involved in the NdFeB magnet industry (e.g., Chemours), or at a more nascent stage of production (e.g., IperionX, Peak Rare Earths). The Department downloaded stock price data for each of these firms and the S&P 500 index from January 1, 2021, through February 24, 2022, from Yahoo Finance. The Department then calculated the daily return of each firm and the S&P 500 index. In line with a simple market model event study, the Department estimated each firm's abnormal return in two steps. For each firm, the Department first regressed the firm's daily return on the S&P 500 index's daily return in a trading window of 250 days to 30 days prior to Russia's invasion of Ukraine (February 24, 2022). The Department then used the estimated coefficients from this regression and the S&P 500 index's daily return to predict the firm's return in a trading window one day prior to one day after the invasion. Finally, the Department subtracted the firm's predicted daily return from the firm's observed daily return to generate an

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[190] Daniel Cordier, "Rare Earths: Mineral Commodity Summaries 2022," U.S. Geological Survey, 2022, https://pubs.usgs.gov/periodicals/mcs2022/mcs2022.pdf.
[191] Ibid.
[192] "Neo Performance Materials MD&A," Neo Performance Materials, 2021, https://www.neomaterials.com/wp-content/uploads/2021/03/NPM_12-31-2020_MDA.pdf.
[193] "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.
[194] Ibid.
[195] For an overview of event studies, *see* e.g., John Binder, "The Event Study Methodology Since 1969," Review of Quantitative Finance and Accounting 11: 111-137, 1998, https://link.springer.com/article/10.1023/A:1008295500105; S.P. Kothari and Jerold B. Warner, "Chapter 1 – Econometrics of Event Studies," Handbook of Empirical Corporate Finance, Volume 1, 2007, https://doi.org/10.1016/B978-0-444-53265-7.50015-9; Abigail McWilliams and Donald Siegel, "Event Studies in Management Research: Theoretical and Empirical Issues," Academy of Management Journal 40 (3): 626-657, 1997, https://doi.org/10.5465/257056.

estimate of the firm's abnormal return in a trading window one day prior to one day after the invasion.

This event study analysis supports market research that suggests the NdFeB magnet industry is not highly exposed to Russia.[196] Using a one sample t-test, the average abnormal return is positive at $p<.05$ with a sample mean of 0.026 and a 95 percent confidence interval of 0.001 to 0.051.[197] A positive abnormal return indicates that firms' stock prices increased more than they would have in the absence of an invasion, suggesting that investors did not expect the invasion to negatively affect the NdFeB magnet industry. Not only is the sign of the abnormal return different than what would be expected if investors believed the invasion would negatively affect the NdFeB magnet industry, but it is statistically significant. This analysis provides additional evidence corroborating the NdFeB magnet industry's lack of exposure to Russia.

To assess whether one firm was driving this result, the Department iteratively dropped each observation, resulting in a sample mean of .018 without Energy Fuels (not significant at $p<.05$), 0.025 without Lynas Rare Earths (not significant at $p<.05$), 0.024 without MP Materials (not significant at $p<.05$), and 0.037 without Neo Performance Materials (significant at $p<.05$). Neo Performance Materials' stock price did not experience as positive an abnormal return as the other three firms', suggesting that investors were relatively less optimistic about the effects of the invasion on Neo Performance Materials. This is consonant with market research expectations, because Neo Performance Materials sources some rare earths from Russia (along with Australia, China, and the United States) and therefore has more direct exposure to Russia than the other three firms.[198]

8. Status and Forecast of the U.S. NdFeB Magnet Industry

8.1 U.S. Production of NdFeB Magnets and Components, 2017 to 2026

This section covers U.S. production of NdFeB magnets and magnet components, including mixed rare earth oxides, rare earth carbonates, individual rare earth oxides, rare earth metals, and rare earth alloys, from 2017 to 2026.[199] It focuses on identifying current and planned producers, their participation in the NdFeB magnet value chain, and the current and anticipated quantity of U.S. production at each value chain step. Later sections will elucidate the challenges the industry faces in meeting its production forecasts.

8.1.1 Firm Participation in the U.S. NdFeB Magnet Value Chain

Except for rare earths mining, the United States was not a major participant in the NdFeB magnet value chain from 2017 to 2021 and only seven firms participated in any step of the NdFeB magnet value chain over this period (*see* Figure 4). [TEXT REDACTED].

The Department forecasts U.S. industry growth starting in 2022, due to a combination of expected demand growth, U.S. Government and private sector interest in supply chain resiliency,

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[196] The Department strongly cautions against overinterpreting the results of this analysis because Russia's invasion was not wholly unanticipated and investors should therefore have partially priced in the costs of conflict, and the sample size is very small. Nevertheless, this analysis provides suggestive evidence of the NdFeB magnet industry's minimal exposure to Russia.

[197] Using a two-day trading window – the day of the event and the day after – results in an average abnormal return of 0.018, not significant at $p<.05$.

[198] "Neo Performance Materials MD&A," Neo Performance Materials, 2021, https://www.neomaterials.com/wp-content/uploads/2021/03/NPM_12-31-2020_MDA.pdf.

[199] [TEXT REDACTED]

and rising rare earths prices. Between 2022 and 2026, ten additional firms indicate they will enter the market while the seven original firms noted in the 2017 to 2021 period plan to continue, and in some cases expand, their operations. A total of 17 firms are expected to participate in the NdFeB magnet value chain by 2026 (*see* Figure 5). [TEXT REDACTED]

[TEXT REDACTED]								
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8.1.2 Production of NdFeB Magnets and Magnet Components, 2017 to 2026

Rare Earth Element Production (Mining and Recycling)

Between 2018 and 2021, U.S. production of NdFeB magnet-related rare earths increased by [TEXT REDACTED] (*see* Figure 6).[200] Between 2022 and 2026, U.S. rare earths production is expected to increase [TEXT REDACTED]. For the full 2018 to 2026 period, U.S. rare earths production is expected to increase by [TEXT REDACTED]. Mining is expected to remain the predominant source of rare earths feedstock, occupying roughly [TEXT REDACTED] of production for the period. Recycling is expected to account for the remaining [TEXT REDACTED].

[200] No production was recorded for 2017.

[TEXT REDACTED]

[TEXT REDACTED]

[TEXT REDACTED] [TEXT REDACTED]

Of the rare earths used in NdFeB magnets, neodymium and praseodymium account for [TEXT REDACTED] of the 2017 to 2026 market, with neodymium making up around [TEXT REDACTED] and praseodymium around [TEXT REDACTED]. Dysprosium production is slated to increase starting in [TEXT REDACTED] and will bring neodymium and praseodymium's combined market share down to [TEXT REDACTED] by 2026. An increase in dysprosium production to over [TEXT REDACTED] in 2026 is significant due to previously cited concerns about single source concentrations in China.[201] Should dysprosium production develop, the United States may become a feasible alternative to China for some dysprosium sourcing.

[TEXT REDACTED]

Rare Earth Carbonates

Between 2023 and 2026, U.S. rare earth carbonates production is expected to increase [TEXT REDACTED] (*see* Figure 7).[202] Of these carbonates, those containing [TEXT REDACTED] are anticipated to be the main driver for this growth, accounting for [TEXT REDACTED] of total carbonates growth. Carbonates containing [TEXT REDACTED] make up most of the remaining production with small amounts of carbonates containing [TEXT REDACTED] expected to be produced starting in [TEXT REDACTED].

[TEXT REDACTED]

[TEXT REDACTED]

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[201] Comments of USA Rare Earth to Request for Public Comments, "Section 232 National Security Investigation of Imports of Neodymium-Iron-Boron (NdFeB) Permanent Magnets," 86 FR 53277, November 12, 2021.

[202] [TEXT REDACTED]

[TEXT REDACTED] [TEXT REDACTED]

[TEXT REDACTED]
Separated Rare Earth Oxides
Between 2023 and 2026, U.S. separated rare earth oxides production is expected to increase [TEXT REDACTED] (*see* Figure 8).[203] Of these oxides, [TEXT REDACTED] are the main driver of growth, accounting for on average [TEXT REDACTED] of total growth. [TEXT REDACTED], most of the remaining growth is due to [TEXT REDACTED] production, with a small [TEXT REDACTED] due to [TEXT REDACTED] and a negligible amount to [TEXT REDACTED].

[TEXT REDACTED]

[TEXT REDACTED]
[TEXT REDACTED]
[TEXT REDACTED] [TEXT REDACTED]

Rare Earth Metals
Between 2023 and 2026, U.S. rare earth metals production is expected to increase by [TEXT REDACTED] (*see* Figure 9).[204] At this production rate, the United States could produce between about [TEXT REDACTED] of NdFeB magnets.[205] Of these metals, [TEXT REDACTED] rare earth metal is the main driver for growth, accounting for on average [TEXT REDACTED] of total rare earth metals growth. [TEXT REDACTED] will make up much of the remaining growth. The Department expects U.S. firms will refine negligible amounts of [TEXT REDACTED].

[TEXT REDACTED]

[TEXT REDACTED]

[203] No production was recorded for 2017 to 2021 [TEXT REDACTED].
[204] No production was recorded for 2017 to 2021 [TEXT REDACTED].
[205] The Department reached this estimate by first calculating the amount of NdFeB alloy [TEXT REDACTED] of rare earth metal could produce based on 30 percent rare earths content in NdFeB magnets, then estimating the range of potential material loss from alloy production to magnet production (*see* Section 5.2, "Rare Earth Element Losses in Magnet Production," for estimates of material loss from alloy production to magnet production).

[TEXT REDACTED]
[TEXT REDACTED] [TEXT REDACTED]

Rare Earth Alloys

Between 2023 and 2026, U.S. rare earth alloys production is expected to increase by [TEXT REDACTED] (*see* Figure 10).[206] At this production rate, the United States would produce enough alloy for between [TEXT REDACTED] of NdFeB magnets.[207] Of these alloys, [TEXT REDACTED] is anticipated to be the main driver of growth, representing on average [TEXT REDACTED] of total alloy growth. Production of [TEXT REDACTED] are expected to represent [TEXT REDACTED] of growth, respectively. NdFeB alloys containing heavy rare earths including dysprosium and terbium are critical for high heat tolerant NdFeB magnets used in products like electric vehicle drive trains.

[TEXT REDACTED]

[TEXT REDACTED]
[TEXT REDACTED]
[TEXT REDACTED] [TEXT REDACTED]

NdFeB Magnet Production

Between 2017 and 2022, no sintered NdFeB magnet production was recorded in the United States. [TEXT REDACTED], commercial-scale production is not expected until 2023. Between

[206] No production was recorded for 2017 to 2021 [TEXT REDACTED].

[207] *See* Section 5.2, "Rare Earth Element Losses in Magnet Production," for estimates of material loss from alloy production to magnet production.

2023 and 2026, U.S. sintered NdFeB magnet production is expected to increase [TEXT REDACTED] to over 14,000 tons (*see* Figure 11).

[TEXT REDACTED].[208]

[TEXT REDACTED]
[TEXT REDACTED]
[TEXT REDACTED]. [TEXT REDACTED]

On average, sintered NdFeB magnet production is expected to account for roughly 97 percent of aggregate U.S. NdFeB magnet production. Although occupying a small portion of the market, it is important to note that domestic bonded NdFeB magnet production existed during the 2017 to 2021 period. Between 2017 and 2021, bonded NdFeB magnet production increased [TEXT REDACTED] (*see* Figure 11). Between 2022 and 2026 production is expected to increase by a further [TEXT REDACTED] from about [TEXT REDACTED], with total production increasing by [TEXT REDACTED] between 2017 and 2026.

[TEXT REDACTED]

8.1.3 Company Profiles

To better illuminate the plans, requirements, and challenges U.S. firms face in establishing production, the Department developed profiles of those firms that are expected to be major participants in the U.S. NdFeB magnet industry (*see* Appendix F, "U.S. NdFeB Magnet Industry: Company Profiles"). [TEXT REDACTED].[209] These profiles emphasize information on current and planned facilities, including location, initial dates of production, and capacity, planned facilities' fixed costs, future production volumes, employment, and challenges.

8.1.4 Estimated NdFeB Magnet Import Penetration, 2017 to 2026

The Department used the data from its survey of the U.S. NdFeB magnet industry and estimates of U.S. NdFeB magnet demand to estimate import penetration for sintered and bonded NdFeB magnets from 2017 to 2026 (*see* Figures 12 and 13).[210] Based on these data and the assumptions

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[208] "General Motors and MP Materials Enter Long-Term Supply Agreement to Scale Rare Earth Magnet Sourcing and Production in the U.S.," General Motors, December 9, 2021, https://investors.gm.com/news-releases/news-release-details/general-motors-and-mp-materials-enter-long-term-supply-agreement.
[209] [TEXT REDACTED]
[210] The Department's figures rely on several demand and export assumptions and should be taken as lower bound for import penetration. U.S. production estimates are taken from the Department's survey and reflect firms' production forecasts as of February and March 2022. The quantity of domestic production in Figures 20 and 21 will require

detailed in footnote 210, the Department estimates sintered NdFeB magnet import penetration from 2017 to 2021 at one hundred percent. There was no domestic production of NdFeB magnets during this period. From 2022 to 2026 import penetration could fall to as low as 49 percent as domestic production ramps up. The Department estimates bonded NdFeB magnet import penetration from 2017 to 2021 at between 85 and 87 percent. This figure is expected to fall to about 79 percent due to expanded U.S. production. The Department emphasizes that, because of the optimistic production estimates and the modelling assumptions detailed in footnote 210, these import penetration estimates should be taken as a floor and actual import penetration is expected to be higher.

Figure 12: Estimated U.S. Sintered NdFeB Magnet Import Penetration, 2017 to 2026, Tons

Figure/Year	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
U.S. Production	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]
U.S. Imports for Consumption*	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]
U.S. Domestic Exports**	-	-	-	-	-	-	-	-	-	-
U.S. Apparent Consumption***	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]
Import Penetration (No Exports)****	100%	100%	100%	100%	100%	99.7%	91%	74%	56%	49%
Source: U.S. Department of Commerce, Bureau of Industry and Security, NdFeB Survey, 3a, Section G.										

significant capital expenditure and faces additional constraints in the form of workforce issues and other challenges, discussed in more detail below. In addition, by relying on production of NdFeB magnets this analysis reflects direct imports only and does not take into account trade in value added. There are several domestic magnet integrators and finishers who purchase magnets or magnet blocks and shape and integrate them into intermediate and final products, some of which are exported. The Department's analysis does not account for these value-add activities. Further, the Department asked firms to only provide sales data if contracts or memorandums of understanding were in place. No prospective U.S. sintered NdFeB magnet producer indicated sales to foreign customers [TEXT REDACTED]. The Department therefore assumed no foreign sales of sintered NdFeB magnets [TEXT REDACTED]. Any foreign sales (i.e., domestic exports) will increase import penetration. The Department used estimates of total U.S. demand provided by the Department of Energy (DoE). DoE estimated total 2020 and 2030 U.S. demand for NdFeB magnets, with the 2030 figure representing a high growth scenario. DoE's demand estimates reflect both direct and embedded demand. [TEXT REDACTED]

Source: “Rare Earth Permanent Magnets: Supply Chain Deep Dive Report,” Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.
*Imports for consumption are calculated as U.S. Apparent Consumption (i.e., total demand) less U.S. production and therefore differs from direct imports.
**No exports recorded (measured in tons) over the period.
*** [TEXT REDACTED]
****Import penetration estimates shown are minimums. Actual figures are expected to be higher due to modelling assumptions and optimistic production estimates.

Figure 13: Estimated U.S. Bonded NdFeB Magnet Import Penetration, 2017 to 2026, Tons

Figure/Year	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
U.S. Production	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]
U.S. Imports for Consumption*	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]
U.S. Domestic Exports**	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]
U.S. Apparent Consumption***	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]	[TEXT REDACTED]
Import Penetration (No Exports)****	87%	87%	87%	85%	87%	86%	86%	85%	79%	79%

Source: U.S. Department of Commerce, Bureau of Industry and Security, NdFeB Survey, 3a, Section G.
Source: “Rare Earth Permanent Magnets: Supply Chain Deep Dive Report,” Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.
* Imports for consumption are calculated as U.S. Apparent Consumption (i.e., total demand) less U.S. production and therefore differs from direct imports.
**[TEXT REDACTED]
*** [TEXT REDACTED]
****Import penetration estimates shown are minimums. Actual figures are expected to be higher due to modelling assumptions and optimistic production estimates.

8.2 Requirements to Establish the U.S. NdFeB Magnet Industry

8.2.1 Facility Costs and Capital Expenditures

As indicated in the earlier section on firm-level profiles, the facilities required to produce NdFeB magnets and components of NdFeB magnets are costly to establish. In meetings with industry stakeholders, company representatives emphasized the substantial investment requirements to establish U.S. capacity. MP Materials announced in 2019 that it was spending $200 million to establish a domestic processing and separation facility and announced in February 2022 plans to spend $700 million to establish a vertically integrated NdFeB magnet supply chain in the United States.[211] [212] [TEXT REDACTED].[213] On the lower end of the spectrum, Quadrant Magnetics announced that it plans to invest $95 million to construct a U.S. NdFeB magnet manufacturing facility, with anticipated capacity of [TEXT REDACTED].[214] Other industry stakeholders, while not reporting specific costs, indicated that expenditures made it difficult to construct facilities without demand from anticipated customers. These figures emphasize the need for increased certainty of demand, ideally through definitive offtake agreements, and the limitations of current U.S. Government funding mechanisms, such as the Title III program, to provide sufficient capital.

The Department's survey provides further evidence on the costs to establish U.S. production facilities. Respondents were asked to list all future facilities that would start production between 2022 and 2026.[215] For each facility, respondents were asked to estimate the total cost it would take to reach full production capacity. There is considerable variation in facility costs between value chain steps (*see* Figure 14). The upstream steps of the value chain are generally the most expensive to establish, with the median mining facility estimated to cost [TEXT REDACTED], and the median oxide facility estimated to cost about [TEXT REDACTED]. In comparison to mining facilities, plants that reclaim/recycle rare earth elements from waste feedstocks are relatively inexpensive at [TEXT REDACTED]. Facility costs are generally lower in the downstream steps of the value chain. Respondents estimate that the median metal facility costs [TEXT REDACTED], the median alloy facility [TEXT REDACTED], and the median sintered NdFeB magnet facility around [TEXT REDACTED].

[TEXT REDACTED]

[211] Ernest Scheyder, "California rare earths miner races to refine amid U.S.-China trade row," Reuters, August 23, 2019, https://www.reuters.com/article/us-usa-rareearths-mpmaterials-idUSKCN1VD2D3.
[212] John Wagner and Amy B. Wang, "Biden announces new spending on mineral production to address supply chain challenges," Washington Post, February 22, 2022, https://www.washingtonpost.com/politics/2022/02/22/biden-minerals-supply-chain-announcement/.
[213] Meeting between USA Rare Earth and the Department of Commerce, (Virtual Meeting, December 10, 2021).
[214] Eleanor Tolbert, "Global Manufacturer Plans $95 million facility in Louisville," Louisville Business First, January 28, 2022, https://www.bizjournals.com/louisville/news/2022/01/28/manufacturer-plans-95-million-facility.html.
[215] Although respondents were asked to provide information on any future facilities regardless of location, respondents only indicated future facilities in the United States or in undecided locations.

[TEXT REDACTED]

[TEXT REDACTED]

Firms face considerable financial shortfalls when it comes to new facilities. Figure 15 shows the median and mean difference at the facility-level between the amount needed to reach full production and amount firms have allocated to reach full production, as well as the sum of differences over facilities, grouped by facility value chain step. The similarity between the median and mean differences between funds need and funds allocated suggest that there are few well-funded outliers. In addition, the differences between funds needed and funds allocated are similar to the facility costs in Figure 14, indicating that most firms have allocated little to no money for the construction of new facilities. The total funding needed to bring all planned facilities online is considerable but varies widely between value chain steps. The seven new sintered NdFeB magnet facilities, which are critical to achieving the ambitious production estimates discussed earlier, are expected to require over [TEXT REDACTED].[216] This is not even the largest shortfall in the NdFeB magnet value chain: [TEXT REDACTED]. Metal and alloy plants have the smallest shortfall, requiring a further [TEXT REDACTED], respectively. As relatively low levels of domestic metal and alloy production are expected to constrain the use of domestic metals and alloys in NdFeB magnets, the comparatively small gap between allocated and required funds for metal and alloy plants is of particular interest. Without substantial new funding, U.S. producers will not meet the production estimates described earlier.

[TEXT REDACTED]

[216] [TEXT REDACTED]

[TEXT REDACTED]
[TEXT REDACTED] [TEXT REDACTED]

Data on firms' capital expenditures from 2017 to 2026 corroborate the significant financing needed to achieve production forecasts. From 2017 to 2020 annual capital expenditures were well under [TEXT REDACTED] annually, reflecting the fact that prior to 2021 the only active domestic value chain steps were mining and bonded NdFeB magnet production (*see* Figure 16). In 2021, capital expenditures increased to just under [TEXT REDACTED] and are forecasted to jump in 2022 to over [TEXT REDACTED]. The massive increase in capital expenditure to around [TEXT REDACTED] annually for 2022 to 2024 is further evidence of the considerable funding needed to establish a U.S. NdFeB magnet value chain.

[TEXT REDACTED]
[TEXT REDACTED]
[TEXT REDACTED] [TEXT REDACTED]

The sources of capital expenditure funding in 2021 indicate the potential need for additional sources of financing to cover anticipated outlays. Even in 2021, when aggregate industry capital expenditure is a comparatively low [TEXT REDACTED], over [TEXT REDACTED] of recorded spending was self-funded (*see* Figure 17). Department of Defense funds covered less than [TEXT REDACTED] of total expenditure. Given Title III funding constraints, it is unlikely that current Department of Defense funding mechanisms will be able to scale support for the U.S. NdFeB magnet industry when annual capital expenditures increase to over [TEXT REDACTED] in 2022. Additional private sector financing that can bolster internal sources of capital expenditure funding will be critical to achieving production estimates.

[TEXT REDACTED]

[TEXT REDACTED]

[TEXT REDACTED] [TEXT REDACTED]

8.2.2 Critical Equipment

In addition to costly facilities, the production of NdFeB magnets and components of NdFeB magnets requires expensive critical equipment. 22 firms indicated 130 pieces of equipment that are critical to production in the Department's survey. Firms identified the most pieces of equipment for NdFeB magnet production [TEXT REDACTED] followed by alloy production [TEXT REDACTED]. Firms identified the fewest pieces of equipment for recycling rare earths [TEXT REDACTED] and mining [TEXT REDACTED].[217]

The most cited source of equipment was the United States, followed by Japan, China, and Germany. The high degree of machinery sourcing from the United States may reflect the location of assembly rather than where machine components were produced. Industry participants indicated that the most sophisticated machinery relevant to NdFeB magnets come from Japan and Germany, with additional equipment sourced from China.[218] Japan was the top source for equipment needed to produce magnets. Respondents indicated equipment also came from [TEXT REDACTED].

Mining equipment was on average the most expensive critical machinery, with a mean of over [TEXT REDACTED] (*see* Figure 18). Machinery to produce magnets was the second most expensive at an average of [TEXT REDACTED], closely followed by oxide production equipment at over [TEXT REDACTED]. Metal production equipment was on average the least expensive at [TEXT REDACTED]. The relative cost of equipment across value chain steps partially reflects the costs of facilities: mining is the most expensive, oxides and magnets are less so, and metals and alloys the least costly.

[TEXT REDACTED]

[217] The distribution of equipment may reflect the composition of our sample.
[218] [TEXT REDACTED]

[TEXT REDACTED]
[TEXT REDACTED]. [TEXT REDACTED]

In addition to cost, some industry representatives have indicated the potential for supply chain issues in the acquisition of necessary capital equipment.[219] The NdFeB magnet industry has, like other industries, seen long lead times, which industry participants tend to attribute to COVID-19-related supply chain issues. Across all pieces of equipment, the average lead time is 238 days, and the median lead time is 240 days. When disaggregating by value chain step, equipment needed to produce carbonates faces somewhat shorter lead times, while equipment needed to produce magnets and oxides faces somewhat longer lead times (*see* Figure 19). There do not appear to be strong patterns when disaggregating by equipment criticality. Equipment that is critical to production tends to face longer lead times across value chain steps, but this is not the case for equipment to produce magnets and the differences are sometimes small. The Department also examined average lead times by source country and value chain step. At the country-level lead times for the United States were somewhat lower than for other countries, although not across all value chain steps. No other strong patterns emerged, in part reflecting the small sample size when cross tabulating the survey data in this way.

[TEXT REDACTED]
[TEXT REDACTED]
[TEXT REDACTED]. [TEXT REDACTED]

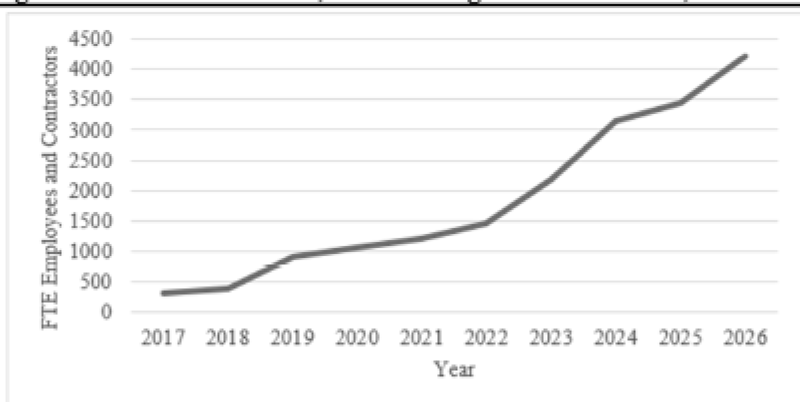
Even within pieces of equipment there is considerable heterogeneity. [TEXT REDACTED]

[219] [TEXT REDACTED].

8.2.3 Employment

The U.S. NdFeB magnet industry directly employs a relatively small number of individuals.[220] Mine to magnet production has increased total full time equivalent (FTE) employment from 314 in 2017 to 1,214 in 2021 and is expected to increase to 4,226 by 2026 as facilities at different steps of the value chain start production (*see* Figure 20). By comparison, employment in the North American Industry Classification System (NAICS) corresponding to NdFeB magnets ("All Other Miscellaneous Fabricated Metal Product Manufacturing" – 332999) was 76,918 in 2020 and employment in the NAICS corresponding to carbonates, oxides, and metals ("Other Basic Inorganic Chemical Manufacturing" – 325180) was 39,700 in 2020. Even assuming no growth in non-NdFeB magnet employment in these NAICS the U.S. NdFeB magnet industry would contribute less than four percent to direct employment in 2026.

Figure 20: U.S. Workforce, NdFeB Magnet Value Chain, 2017-2026



Source: U.S. Department of Commerce, Bureau of Industry and Security, NdFeB Survey, 6, Part A.
[TEXT REDACTED].

Respondents: 17

As mentioned earlier, the U.S. NdFeB magnet industry is emerging and many of the firms involved plan to expand production and enter other value chain steps. To better understand which occupations will likely be in demand, the Department compared employment by occupation between mature magnet firms and the current U.S. industry. Three mature magnet firms provided employment data in their responses to the Department's survey.[221] These firms are established NdFeB magnet producers with significant output and provide insight into the employment makeup of a typical magnet firm. Figure 21 compares the mean proportion employed in each of five broad occupational categories between these two samples. Mature magnet firms employ relatively similar proportions across occupational categories: [TEXT REDACTED] are manufacturing engineers, scientists, and research and development (R&D); approximately [TEXT REDACTED] are in production line operations; around [TEXT REDACTED] in sales, administrative, and management; about [TEXT REDACTED] in testing

[220] The Department notes that this does not consider employment in the many sectors that rely on NdFeB magnets, such as electric vehicles and wind turbines.
[221] [TEXT REDACTED]

and quality control; and [TEXT REDACTED] in information technology. By contrast, as indicated by the wide standard deviations, current U.S. producers are very heterogeneous in the proportion employed across occupational categories. They also employ a far smaller percentage of production line operations employees (about [TEXT REDACTED]). Based on occupational data from current mature magnet producers, U.S. firms are likely to employ a greater percentage of production line operations employees as they develop capacity.

[TEXT REDACTED]
[TEXT REDACTED]
[TEXT REDACTED]. [TEXT REDACTED]

Industry stakeholders indicated to the Department a range of perspectives on employment challenges. For example, MP Materials stated that the United States "has limited skilled labor and human resources needed for the production of this high-technology product."[222] In contrast, the United States Magnetic Materials Association said that "the knowledge of how to produce the magnets does exist" and cited the inability to obtain licenses for critical intellectual property and return on investment as more significant barriers to domestic production.[223] This is consistent with Arnold Magnetics' public comments, in which it indicated it could shift production from Samarium-Cobalt magnets to NdFeB magnets.[224] [TEXT REDACTED].

[222] Comments of MP Materials to Request for Public Comments, "Section 232 National Security Investigation of Imports of Neodymium-Iron-Boron (NdFeB) Permanent Magnets," 86 FR 53277, November 12, 2021.
[223] Comments of the United States Magnetic Materials Association to Request for Public Comments, "Section 232 National Security Investigation of Imports of Neodymium-Iron-Boron (NdFeB) Permanent Magnets," 86 FR 53277, November 12, 2021.
[224] Comments of Arnold Magnetics to Request for Public Comments, "Section 232 National Security Investigation of Imports of Neodymium-Iron-Boron (NdFeB) Permanent Magnets," 86 FR 53277, November 12, 2021.

Survey respondents were requested to indicate what labor market issues they faced, including the timeframe and the primary affected occupation. For U.S. producers, the primary workforce issues faced were finding qualified and experienced workers, followed by attracting workers to their location and finding U.S. citizens (*see* Figure 22). U.S. producers were likely to select high wage occupations as the primary occupation affected and were much more likely to do so when compared to non-producers, although production line operations were also frequently cited. The U.S. NdFeB magnet industry may face human capital challenges, in particular finding engineers and scientists.

[TEXT REDACTED]
[TEXT REDACTED]
[TEXT REDACTED]. [TEXT REDACTED]

Qualitative survey responses provide further evidence of the NdFeB magnet industry's potential difficulties in attracting human capital. The lack of available and experienced high wage labor was a particularly common refrain. [TEXT REDACTED]

Firms that can find workers face competition and difficulties attracting them. [TEXT REDACTED] Many NdFeB magnet firms are located outside major urban centers, which can cause issues attracting talent. [TEXT REDACTED]

8.3 Additional Challenges to Domestic Production

8.3.1 Import Competition, Production Costs, and General Challenges

The Department's survey of the U.S. NdFeB magnet industry asked firms about whether they struggled to compete against imports. 29 firms – 57 percent of the sample and 67 percent of current or planned U.S. NdFeB magnet value chain producers – responded affirmatively. The Department then asked the percentage of operating costs attributable to eight input conditions. Figure 23 shows the median cost for each input condition for all respondents, non-producers, current or planned U.S. producers, and foreign producers.[225] Producers indicated that feedstock purchases are the single largest contributor to operating costs. [TEXT REDACTED]. By contrast, non-producers indicated sourcing feedstock is a distant second to labor costs. This is consonant with the high cost of rare earths in NdFeB magnets. The cost of sourcing feedstock is

[225] Proportions do not sum to one for each category because firms were not compelled to complete this section. In addition, there is an "Other" category that is mainly described as miscellaneous or overhead costs.

one vector of Chinese competition. [TEXT REDACTED]. Labor is the second largest contributor to U.S. producer operating costs, representing about [TEXT REDACTED], followed by electricity at [TEXT REDACTED].

[TEXT REDACTED]
[TEXT REDACTED]
[TEXT REDACTED]. [TEXT REDACTED]

The Department also asked survey respondents to indicate which of 30 challenges affected their competitive position and to rank the top five challenges (*see* Figure 24). Foreign competition is the most important challenge for U.S. NdFeB magnet industry participants. [TEXT REDACTED] current and future U.S. producers ranked foreign competition in their top five challenges, and [TEXT REDACTED] current and future U.S. producers ranked it as their number one challenge. [TEXT REDACTED] of current and future U.S. producers ranked input availability as their number one challenge, making it the second most frequently cited number one challenge. [TEXT REDACTED] current and future U.S. producers included labor availability in their top five challenges, making it the second most frequently cited challenge overall. Current and future U.S. producers also indicated financing/credit availability is an issue, with [TEXT REDACTED] of respondents ranking it in their top five challenges. [TEXT REDACTED] U.S. producers also indicated financing/credit availability is a minor issue, with only [TEXT REDACTED] including it in their top five challenges.

[TEXT REDACTED]

[TEXT REDACTED]	[TEXT REDACTED]
[TEXT REDACTED]. [TEXT REDACTED]	

Qualitative explanations underscore foreign competition, in particular with China, as a major challenge for domestic production. Many respondents who cited foreign competition directly compete with Chinese firms, which they claim are unfairly advantaged through government policies, subsidies, and market manipulation. Several respondents noted that the lack of environmental regulations and enforcement in China allows Chinese magnet producers to undercut prices for NdFeB magnets. Others noted the near total domination that Chinese firms had throughout the NdFeB magnet supply chain, which enables China to set market prices. China is also mentioned in terms of input availability. Some firms indicate that there are few sources of feedstocks outside of China [TEXT REDACTED]. Chinese firms also compete with U.S. producers for inputs. [TEXT REDACTED]

Respondents were also likely to cite Chinese competition as the primary challenge to increasing their market share. One U.S. magnet integrator noted that China is a low-cost producer of NdFeB magnets and end-users often purchase from the cheapest source regardless of country of origin. Other respondents reiterated that Chinese suppliers are unfairly subsidized and because of their dominant position can set prices. A related factor cited by one U.S. producer is the higher cost of labor in the United States compared to foreign competitors. Another often-mentioned challenge to expanding operations and market share is accessing the necessary financing for capital investments. Finally, several respondents experienced challenges in developing a resilient supply chain for their operations, such as securing diverse sources for necessary feedstocks. Domestic sources are a particular challenge given the lack of U.S. production capacity in all stages of the

NdFeB magnet value chain. Reflecting the more general challenges discussed earlier, Chinese competition, feedstocks, and capital are major barriers to expanding production.

8.3.2 Environmental Factors

Rare earths mining and processing can cause damage to the environment because it produces large amounts of hazardous and radioactive waste.[226] Mining waste, also known as tailings, is typically stored in impoundments engineered to minimize waste seepage.[227] [228] Further downstream the value chain, the disposal and recycling of electronic waste can release heavy metals into the environment, with negative consequences for natural ecosystems.[229] In countries with less-stringent environmental regulations such as China, heavy metals can reach and contaminate groundwater during the mining process.[230] By contrast, environmental regulation in more highly-regulated economies pose additional costs and risks to market participants.[231] [232] For example, a Government Accountability Office report found that between 2010 and 2014 it took the Department of the Interior's Bureau of Land Management and the Department of Agriculture's Forest Service between one month and 11 years to approve mine plans, with an average approval time of two years.[233] Of the 68 mine plans reviewed, 13 had not begun operations in November 2015, partially attributed to the need to obtain other required federal and state permits.[234] Environmental studies are a time-intensive part of the permitting process.[235] Meanwhile, regulation requirements for depolluting infrastructure increase U.S. production costs.[236] Table 8 displays a non-exhaustive list of relevant statutes and treaties.[237]

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[226] Gwenolyn Bailey, Nabeel Mancheri, and Karel Van Acker, "Sustainability of Permanent Rare Earth Magnet Motors in (H)EV Industry," Journal of Sustainable Metallurgy 3: 611-626, 2017, https://link.springer.com/article/10.1007/s40831-017-0118-4.

[227] "What are Tailings," Society for Mining, Metallurgy, and Exploration, n.d., https://www.smenet.org/What-We-Do/Technical-Briefings/What-are-Tailings.

[228] Mining waste, such as coal tailings and heavy mineral sands, can be processed and recycled to extract contained rare earth elements. [TEXT REDACTED] Austyn Gaffney and Dane Rhys, "In coal country, a new chance to clean up a toxic legacy," Washington Post, May 19, 2022, https://www.washingtonpost.com/climate-solutions/2022/05/19/coal-mining-waste-recycling/.

[229] Duc Huy Dang et al., "Toward the Circular Economy of Rare Earth Elements: A Review of Abundance, Extraction, Applications, and Environmental Impacts," Archives of Environmental Contamination and Toxicology 81: 521-530, 2021, https://link.springer.com/article/10.1007/s00244-021-00867-7.

[230] Gwenolyn Bailey, Nabeel Mancheri, and Karel Van Acker, "Sustainability of Permanent Rare Earth Magnet Motors in (H)EV Industry," Journal of Sustainable Metallurgy 3: 611-626, 2017, https://link.springer.com/article/10.1007/s40831-017-0118-4.

[231] Environmental regulations are critical for public health and safety. Noting that highly regulated jurisdictions are associated with higher production costs is a strictly factual observation and is not an endorsement of deregulation.

[232] Another example of risk is Lynas Rare Earths' Malaysian separation facility, which has brought the company into conflict with the Malaysian government over waste disposal. Currently, Lynas plans to establish a disposal facility as a condition of their license. Interview with Kristin Vekasi, "China's Control of Rare Earth Metals," The National Bureau of Asian Research, August 13, 2019, https://www.nbr.org/publication/chinas-control-of-rare-earth-metals/; "2021 Annual Report," Lynas Rare Earths, Ltd., 2021, https://wcsecure.weblink.com.au/pdf/LYC/02434182.pdf.

[233] "Hardrock Mining: BLM and Forest Service Have Taken Some Actions to Expedite the Mine Plan Review Process but Could Do More," United States Government Accountability Office, January 2016, https://www.gao.gov/assets/gao-16-165.pdf.

[234] Ibid.

[235] Duc Huy Dang et al., "Toward the Circular Economy of Rare Earth Elements: A Review of Abundance, Extraction, Applications, and Environmental Impacts," Archives of Environmental Contamination and Toxicology 81: 521-530, 2021, https://link.springer.com/article/10.1007/s00244-021-00867-7.

[236] Gwenolyn Bailey, Nabeel Mancheri, and Karel Van Acker, "Sustainability of Permanent Rare Earth Magnet Motors in (H)EV Industry," Journal of Sustainable Metallurgy 3: 611-626, 2017, https://link.springer.com/article/10.1007/s40831-017-0118-4.

[237] In addition to the listed statutes and treaties, firms face state and local as well as further federal regulations. For example. MP Materials notes their activities are subject to federal, state, and local laws and regulations covering a wide range of issues, such as air emissions, water usage, and waste management. The Mountain Pass Mine, for

Table 8: Partial List of Relevant Federal and International Environmental Regulations			
Name	**Scope**	**Relevant Body**	**Brief Summary**
Atomic Energy Act of 1954	Waste	Federal	The Nuclear Regulatory Commission ("NRC") oversees the regulatory framework governing the control of radioactive materials, including beneficiation and processing of rare earths that contain radioactive source materials.
Basel Convention	Waste	International	The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes is an international treaty signed in 1989 and entered into force in 1992. It currently has 188 signatories and establishes a "notice and consent" regime for the export of hazardous waste to other countries. The United States is not currently a party to the Basel Convention.
Clean Air Act	Air	Federal and State	Authorizes the Environmental Protection Agency (EPA) to establish national ambient air quality standards and maximum achievable control technology emission standards for hazardous and toxic pollutants. Establishes an air quality control permitting program implemented by EPA and authorized states.
Clean Water Act	Water	Federal and State	Authorizes EPA to establish national water quality criteria and establishes two permitting programs. The National Pollutant Discharge Elimination System (NPDES) Program prohibits the discharge of pollutants through a point source into a water of the United States without a NPDES permit. NPDES permits are issued by EPA or authorized states. The NPDES permit program also includes "Effluent Guidelines," including the Mineral Mining and Processing Effluent Guidelines and Standards, the Ferroalloy Manufacturing Effluent Guidelines and Standards, and the Metal Finishing Effluent Guidelines. Clean Water Act section 404 permits, issued by the U.S. Army Corps of Engineers or authorized states, are required for the discharge of

instance, has 16 environmental permits from 11 entities with various expiration dates. *See* "Form 10-K," MP Materials, February 28, 2022, https://d18rn0p25nwr6d.cloudfront.net/CIK-0001801368/77b2894e-b746-43c5-938a-a3f524823baa.pdf.

			dredge and fill material in waters of the United States.
Comprehensive Environmental, Response, Compensation and Liability Act	Waste	Federal	Provides Federal authority for responding to releases or threatened releases of hazardous substances that may endanger public health or the environment.
The Endangered Species Act	General	Federal	Regulates activities that could have an adverse effect on threatened and endangered species, including the habitat and ecosystems upon which they depend.
Federal Mine Safety and Health Act of 1977, as amended by the Mine Improvement and New Emergency Response Act of 2006	Mining	Federal	Imposes health and safety standards on mining operations, including training of mine personnel, mining procedures, blasting, the equipment used in mining operations and other matters. In 2006, the Mine Safety and Health Administration promulgated new emergency mine safety rules addressing mine safety equipment, training, and emergency reporting requirements.
Mobile Phone Partnership Initiative (MPPI)	Waste	International	Launched in 2002 to promote awareness raising - design considerations, collection of used and end-of-life mobile phones, transboundary movement of collected mobile phones, refurbishment of used mobile phones, and material recovery/recycling of end-of-life mobile phones. Has not met since 2011.
The National Environmental Policy Act	General	Federal	Requires Federal agencies to integrate environmental considerations into certain decision-making processes by evaluating the environmental impacts of their proposed actions, including issuance of permits to mining facilities, and assessing alternatives to those actions.
Partnership for Action on Computing Equipment (PACE)	Waste	International	Developed as a multi-stakeholder public-private partnership that provides a forum for representatives of personal computer manufacturers, recyclers, international organizations, associations, academia, environmental groups, and governments to tackle environmentally sound refurbishment, repair, material recovery, recycling, and disposal of used and end-of-life computing equipment.
Resource Conservation and	Waste	Federal and State	Gives the EPA and authorized states the authority to regulate hazardous from cradle

Recovery Act (RCRA)			to grave under Subtitle C. RCRA establishes the framework for a national system of solid waste control where EPA sets minimum national technical standards for how disposal facilities should be designed and operate. States play the lead role under Subtitle D. Most extraction and beneficiation wastes from hardrock mining are excluded from federal hazardous waste regulations under Subtitle C.
The Safe Drinking Water Act	Water	Federal and State	Authorizes EPA to establish standards to protect underground sources of drinking water and establishes the underground injection control program that regulates the drilling and operation of subsurface injection wells. Permits are issued by EPA or authorized states.

The Department used data from its survey of the U.S. NdFeB magnet industry, a previous industrial base assessment on rare earth elements, meetings with NdFeB magnet industry participants, and market research to assess the relationship between the NdFeB magnet value chain and environmental regulations. Based on these data, a preliminary picture emerged that although historically NdFeB magnet industry participants saw environmental factors as a constraint, the current NdFeB magnet industry is using new methods and technologies to reduce its environmental impact and sees these processes as enabling competition with China, even though weaker Chinese environmental regulations increase the price gap between Chinese and non-Chinese magnets.

In 2014 the Department conducted a survey under section 705 of the DPA of U.S. rare earth suppliers and product manufacturers to support a 2016 supply chain assessment on dysprosium, erbium, neodymium, terbium, and ytterbium called "U.S. Strategic Material Supply Chain Assessment: Select Rare Earth Elements" ("2016 Rare Earths Assessment"). Of the 160 respondents, 126 indicated they used one of the rare earths that make up NdFeB magnets – neodymium, praseodymium, terbium, or dysprosium – and 115 indicated they used neodymium.

These survey data suggest that in the early 2010s environmental factors constrained multiple steps in the U.S. rare earths value chain. 36 respondents (22.5 percent) indicated that environmental regulations/remediation had a current and/or future impact on their rare earth element-related business lines.[238] Upstream in the value chain, mining firms stated environmental regulations were a source of concern. [TEXT REDACTED] The impact of environmental regulations propagated downstream to customers. [TEXT REDACTED]

In contrast, the current U.S. NdFeB magnet industry sees environmental factors as a relatively minor concern and cites environmentally friendly technologies as a source of opportunity. The Department's survey of the U.S. NdFeB magnet industry asked firms to identify the primary

[238] This analysis uses the larger sample of companies involved in any NdFeB magnet-related rare earths production, except when stated otherwise.

challenges affecting their competitive positions and rank the top five from a list of 30 potential responses. Among the 16 current or future U.S. producers that provided responses, [TEXT REDACTED]. Restricting the sample to the top five challenges, environmental regulations are tied with four other issues for the seventh most cited challenge. [TEXT REDACTED] These data suggest that environmental regulations matter but are relatively less important in comparison to the other challenges faced by the U.S. NdFeB magnet industry.

Input cost data from the Department's survey of the U.S. NdFeB magnet industry lend support for the view that environmental regulations are minor in comparison to other factors. The Department's survey asked respondents to estimate the percentage of operating costs due to a series of inputs, including environmental regulations. The median response from current or planned U.S. producers regarding environmental regulations was [TEXT REDACTED], lower than sourcing feedstock material ([TEXT REDACTED]), labor ([TEXT REDACTED]), other ([TEXT REDACTED], most often described as operating or overhead costs), electricity ([TEXT REDACTED]), transportation costs ([TEXT REDACTED]), and taxes ([TEXT REDACTED]). Only VAT taxes/tariffs/trade duties ([TEXT REDACTED]) and export regulations ([TEXT REDACTED]) ranked lower.

Environmental regulations increase the price gap between Chinese and non-Chinese NdFeB magnets, but consonant with their minor contribution to U.S. firms' production costs their impact appears to be small relative to other factors.[239] [TEXT REDACTED].[240] [TEXT REDACTED].[241] [TEXT REDACTED]. However, other industry participants tend to attribute differences in NdFeB magnet production costs more to Chinese tax policies or energy costs than environmental regulations[TEXT REDACTED].[242] Despite the minor role of environmental regulations, any price gaps can affect customer behavior. [TEXT REDACTED].[243]

Both upstream and downstream in the NdFeB magnet value chain, some firms see environmental factors as a competitive advantage and tout their small environmental footprints and new technologies that help minimize environmental waste.[244] [TEXT REDACTED].[TEXT REDACTED].[245] [TEXT REDACTED].[246] [247] [TEXT REDACTED].[248] [TEXT REDACTED].

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[239] However, in response to the Department's survey of the U.S. NdFeB magnet industry only [TEXT REDACTED] current or future U.S. producers (of 11 who provided responses) indicated that changing government regulations or incentives around environmental regulations would improve price competitiveness.
[240] Kazuaki Kobayashi, "Trusted Supply-Chain for Rare Earths in the Age of Carbon Neutrality," Ministry of Economy, Trade, and Industry, n.d.
[241] Meeting between the Ministry of Economy, Trade, and Industry and the Department of Commerce, (Virtual Meeting, December 21, 2021)
[242] Meeting between Neo Performance Materials and the Department of Commerce, the Department of Defense, and the U.S. Geological Survey, (Virtual Meeting, November 30, 2021).
[243] Meeting between Lynas Rare Earths and the Department of Commerce, (Virtual Meeting, March 30, 2022).
[244] This anecdotal evidence is consistent with a view that environmental regulation may spur technological innovation and reduce marginal costs. Some research suggests that this process has meant environmental regulations have had no to a positive effect on rare earths exports from China. An Pan et al., "How environmental regulation affects China's rare earth export?," PLoS One 16 (4), 2021, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8062019/.
[245] Meeting between MP Materials and the Department of Commerce, (Virtual Meeting, November 17, 2021).
[246] Energy Fuels briefing to the NSTC Critical Minerals Subcommittee, (Virtual Meeting, November 29, 2021).
[247] [TEXT REDACTED]. Meeting between Energy Fuels and the Department of Commerce, (Virtual Meeting, March 1, 2022).
[248] Meeting between USA Rare Earth and the Department of Commerce, (Virtual Meeting, December 10, 2021).

Downstream in the value chain, Noveon highlighted its low environmental impact, [TEXT REDACTED].[249] Joint research with Purdue University suggests a 50 percent net reduction across a range of environmental indicators, including smog formation, acidification, and respiratory effects.[250] [251] [TEXT REDACTED].[252] NdFeB magnet industry participants throughout the value chain emphasize their low environmental impact and suggest that their more environmentally friendly technologies could act as a competitive advantage in the global marketplace.

8.3.3 Intellectual Property

NdFeB magnets were concurrently invented in 1983 by General Motors in the United States and by Sumitomo in Japan.[253] General Motors commercialized its intellectual property by founding Magnequench, which was eventually acquired by the Canadian firm Neo Performance Materials. The Sumitomo intellectual property passed to Hitachi, which has an extensive NdFeB magnet-related patent portfolio of over 600 patents, including about one hundred U.S. patents.[254] Of these, there are four key U.S. patents for sintered NdFeB magnets that expired in 2021 or will expire in 2022.[255] Other relevant patents with longer expiration dates may exist.[256] In the public comments received for this investigation, many U.S. companies noted that Hitachi has repeatedly declined to offer licenses to U.S. companies. Hitachi granted licenses to eight Chinese firms as early as 2013, which facilitated Chinese firms' entrance in to the sintered NdFeB magnet market.[257] [258] [TEXT REDACTED] [259] Additional Chinese firms may gain de jure access to Hitachi licenses as a result of a 2021 ruling by the Ningbo Intermediate People's Court in China in which NdFeB magnet licenses were held to be essential facilities.[260] Under the essential

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249 Meeting between Noveon and the Department of Commerce, (Virtual Meeting, November 12, 2021).

250 "With Urban Mining, Recycled Bird Magnets are Transforming our Electric Future," Bird Cities Blog, June 6, 2021, https://www.bird.co/blog/urban-mining-recycled-bird-magnets-transforming-electric-future/.

251 Hongyue Jin et al., "Comparative Life Cycle Assessment of NdFeB Magnets: Virgin Production versus Magnet-to-Magnet Recycling," Procedia CRIP 48: 45-50, 2016, https://www.sciencedirect.com/science/article/pii/S2212827116006508.

252 Meeting between Noveon and the Department of Commerce, (Virtual Meeting, November 12, 2021).

253 The method developed by General Motors to produce NdFeB magnets is the predecessor to bonded magnets. The method developed by Sumitomo is the predecessor of sintered NdFeB magnets. Hitachi is an organizational descendent of Sumitomo and therefore holds the intellectual property for sintered magnets.

254 "Chinese Court Enforces Mandatory Licensing for "Essential Facility" Patents in Antitrust Case," Jones Day, June 2021, https://www.jonesday.com/en/insights/2021/06/chinese-court-enforces-mandatory-licensing-for-essential-facility-patents-in-antitrust-case.

255 Some industry participants expressed concern that Hitachi may attempt to renew these patents, but the Department could not locate information on whether Hitachi had done so. Industry participants also mentioned that Bain Capital's potential acquisition of Hitachi Metals may shape Hitachi's behavior. For information on Bain Capital's potential acquisition of Hitachi Metals, *see* Appendix E, "Global NdFeB Magnet Production: A Firm Level Perspective" at footnote 144. [TEXT REDACTED].

256 "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

257 Nathan Bush and Ray Xu, "Framing patents as essential facilities in Chinese antitrust: Ningbo Ketian Magnet Co., Ltd. v. Hitachi Metals," DLA Piper, September 7, 2021, https://www.dlapiper.com/en/us/insights/publications/2021/09/antitrust-matters-september-2021/framing-patents-as-essential-facilities-in-chinese-antitrust/.

258 "Chinese Court Enforces Mandatory Licensing for "Essential Facility" Patents in Antitrust Case," Jones Day, June 2021, https://www.jonesday.com/en/insights/2021/06/chinese-court-enforces-mandatory-licensing-for-essential-facility-patents-in-antitrust-case.

259 U.S. Department of Commerce, Bureau of Industry and Security, NdFeB Survey, 10, Part D.

260 "Chinese Court Enforces Mandatory Licensing for "Essential Facility" Patents in Antitrust Case," Jones Day, June 2021, https://www.jonesday.com/en/insights/2021/06/chinese-court-enforces-mandatory-licensing-for-essential-facility-patents-in-antitrust-case.

facilities doctrine, a firm that controls an essential facility is obliged to make that facility available to competitors on non-discriminatory terms.[261] Hitachi has appealed the case, but may be required to license sintered NdFeB magnet patents to additional Chinese firms.

Hitachi has also defended its intellectual property rights in U.S. courts. In 2012, Hitachi filed a complaint with the United States International Trade Commission (U.S. ITC) against 29 manufacturers and importers of sintered rare earth magnets and products containing sintered rare earth magnets.[262] It sought an exclusion order prohibiting imports of these unlicensed NdFeB magnets and cease and desist orders to produce NdFeB magnets.[263] Some defendants settled with Hitachi, with five Chinese firms agreeing to new licenses. In 2013 Hitachi announced additional settlements and withdrew the U.S. ITC case. Later, some defendants filed for inter partes review with the United States Patent and Trademark Office, which granted the request and found the challenged claims obvious.[264] In an appellate opinion in 2017, the United States Court of Appeals for the Federal Circuit largely affirmed this ruling.[265] U.S. industry participants noted these actions instigated considerable discussion in the NdFeB magnet industry and deterred potential market entrants.[266]

In conversations with industry participants Hitachi's ownership of sintered NdFeB magnet patents was characterized on a spectrum from a critical barrier to entry to a nonexistent risk.[267] Arnold Magnetics considered Hitachi's patents to be a key barrier to market entry and indicated it could produce sintered NdFeB magnets if it had a license.[268] [TEXT REDACTED].[269] [TEXT REDACTED].[270] Some industry representatives also expressed hope that the acquisition of Hitachi's magnets business by Bain Capital may change Hitachi's willingness to license the patents to potential market entrants.[271] In contrast, Noveon relies on new proprietary technology to process recycled magnets and produce new material and is therefore unaffected by Hitachi's reluctance to license its patents. A related concern is whether magnets would need to be produced under licensed patents to be incorporated into some end-user's assemblies and, if so, how expensive qualification of alternative production methods may be. For example, some end-users may qualify magnets for use in their products based on the technology used to produce the magnets.

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[261] There is no accepted definition of essential facility. *See* Christopher Seelen, "The Essential Facilities Doctrine: What Does It Mean To Be Essential?," Marquette Law Review (80), Summer 1997, https://scholarship.law.marquette.edu/cgi/viewcontent.cgi?article=1517&context=mulr.
[262] Walter T. Benecki, "Hitachi Metals, Ltd. The Magner Industry Newsmaker," Magnetics: Business and Technology, November 26, 2013, https://magneticsmag.com/hitachi-metals-ltd-the-magnet-industry-newsmaker/.
[263] Ibid.
[264] Anthony McCain, "Patentlyo Bits and Bytes," Patentlyo, July 31, 2017, https://patentlyo.com/2017/07.
[265] "Hitachi Metals, Ltd., v. Alliance of Rare-Earth Magnet Industry," United States Court of Appeals for the Federal Court, July 6, 2017, https://cafc.uscourts.gov/sites/default/files/opinions-orders/16-1824.Opinion.7-5-2017.1.PDF.
[266] [TEXT REDACTED].
[267] Meeting between Arnold Magnetics and the Department of Commerce, (Virtual Meeting, December 6, 2021); Meeting between USA Rare Earth and the Department of Commerce, (Virtual Meeting, December 10, 2021); Meeting between Noveon and the Department of Commerce, (Virtual Meeting, November 12, 2021).
[268] Comments of Arnold Magnetics to Request for Public Comments, "Section 232 National Security Investigation of Imports of Neodymium-Iron-Boron (NdFeB) Permanent Magnets," 86 FR 53277, November 12, 2021.
[269] Meeting between USA Rare Earth and the Department of Commerce, (Virtual Meeting, December 10, 2021).
[270] Ibid.
[271] For information on Bain Capital's potential acquisition of Hitachi Metals, see Appendix E, "Global NdFeB Magnet Production: A Firm Level Perspective" at footnote 144.

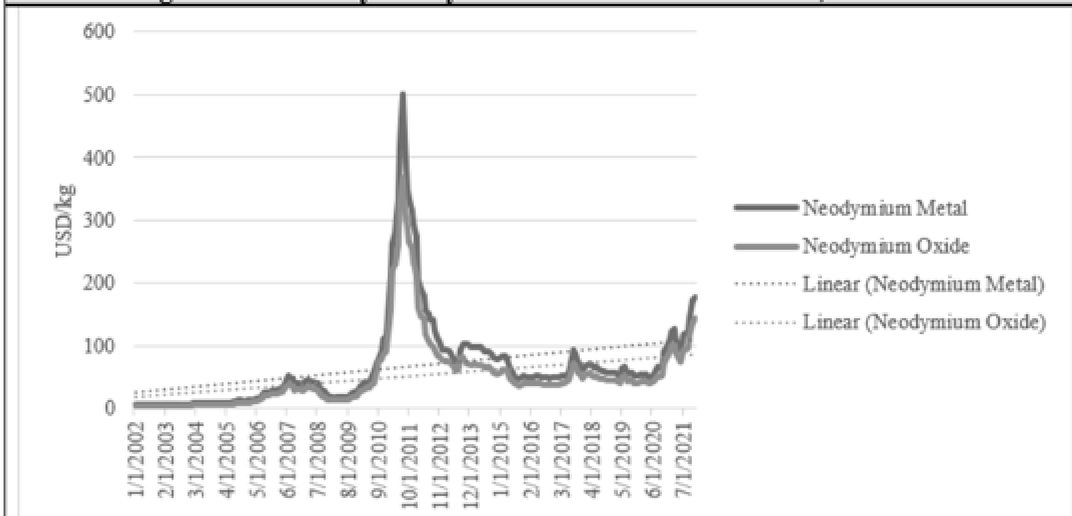
The Department's survey of the U.S. NdFeB magnet industry supports the view that intellectual property does not pose a major barrier to NdFeB magnet production, although access to Hitachi's technology would facilitate domestic production. In response to the question, "Has your organization encountered difficulties in obtaining NdFeB Magnet related IP?" [TEXT REDACTED]. Intellectual property is unlikely to derail current production estimates but may pose constraints on growth and use.

8.3.4 Prices and Price Volatility

NdFeB Magnet Feedstock Prices and Price Volatility

In comparison to NdFeB magnets, neodymium oxide and metal are relatively standard products for which comparable price data are available. Neodymium oxide and metal prices have seen considerable shifts over the previous 20 years (*see* Figure 25). Oxide and metal price changes are closely related because neodymium oxide is processed into neodymium metal.[272] Price data indicate two periods of relative stability (2002 to mid-2010 and 2013 to mid-2020) punctuated with two sharp price increases corresponding to China's cuts to its export quotas in the early 2010s and the early 2020s' rise in prices, which may reflect increased demand.[273] The overall trendline from 2002 to 2021 is of increasing prices – neodymium oxide prices increased by 3,209 percent from \$4.3 per kg in 2002 to \$142.3 per kg in 2021, while neodymium metal prices increased by 2,443 percent from \$7 per kg in 2002 to \$178 per kg in 2021.[274] [275]

Figure 25: Monthly Neodymium Oxide and Metal Price, 2002-2021



Source: The Department's calculations from Bloomberg data, NDCNRGYY Index.

Although the neodymium oxide and metal price series appear to indicate high volatility, prices of neodymium and other rare earth elements used in NdFeB magnets are less volatile than other

[272] The daily price of neodymium oxide and the daily price of neodymium metal are almost perfectly positively correlated at 0.99.

[273] In contrast to the early 2010s spike, there is not a clear cause for the price increases that have occurred since mid-2020. Increased demand from end-users is the most common explanation, based on meetings with industry.

[274] Dysprosium oxide and terbium oxide prices have also increased. Dysprosium oxide prices are up almost 120 percent and terbium oxide prices increased over 375 percent from January 2017 to mid-April 2022, compared to over 265 percent and 188 percent for neodymium oxide and praseodymium oxide, respectively. *See* "Rare Earth 2022 April 18," The Rare Earth Observer, April 18, 2022, https://treo.substack.com/p/shanghai-infinite-lockdown-price?s=r.

[275] For comparison, China's consumer price index increased by an average of 2.2 percent, with a range of -0.7 to 5.9 percent. *See* "Inflation, consumer prices (annual %) – China," World Bank World Development Indicators, last accessed May 17, 2022, https://data.worldbank.org/indicator/FP.CPI.TOTL.ZG?locations=CN.

metals and materials. DoE estimated price volatility for the four key rare earth oxides used in NdFeB magnets (neodymium, praseodymium, dysprosium, and terbium), by analyzing changes in monthly average prices between January 2010 and June 2020, a period that includes the early 2010s price spike but not the more recent rise in prices. DoE found that price volatility was 0.1 for neodymium oxide, 0.09 for praseodymium oxide, 0.13 for dysprosium oxide, and 0.14 for terbium oxide, lower than the average of a set of 30 by-product metals and materials.[276] However, DoE still emphasizes the potential for large price swings, citing the high price volatility resulting from Chinese government policies in the early 2010s.[277]

Industry representatives emphasize the distortionary effects of price volatility. [TEXT REDACTED]. The Chinese government has recently expressed concern about rising prices, calling on major Chinese rare earths producers to maintain a steady supply chain and reduce price increases.[278] Anecdotally, price increases do not appear to have strongly negatively affected Chinese firms in the value chain. For example, "Advanced Technology & Materials, a Chinese producer of NdFeB magnets, [said] the rare earth price increase has had "little impact" on the company because it has a guaranteed supply of raw materials at "favorable prices" from the state-owned giant China Northern Rare Earth Group."[279]

Price increases also have the potential to change consumer behavior and lead to greater interest in substitutes and alternatives. [TEXT REDACTED].[280] Neo Performance Materials also said heightened prices could incentivize substitution research.[281] [TEXT REDACTED].[282]

8.4 Recycling and Substitution

8.4.1 NdFeB Magnet Recycling

Recycling NdFeB magnets or NdFeB magnet swarf, the waste produced by shaping magnets, represents a potentially significant and largely untapped source of rare earth material.[283] In an extreme example, if all U.S. computer hard disk drives (HDDs) were recycled, the contained NdFeB magnets could satisfy up to 80 percent of electric vehicle magnet demand.[284] One market research firm estimates that in 2030 upwards of 90,000 tons of NdFeB magnets will be entering waste streams globally, equal to 23 percent of projected 2030 demand.[285] In the past 15 years,

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[276] Michael Redlinger and Roderick Eggert, "Volatility of by-product metal and mineral prices," Resources Policy, 47: 69–77, 2016, https://doi.org/10.1016/j.resourpol.2015.12.002.

[277] "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

[278] "China Calls on Rare Earths Companies to Bring Prices Back to "Reasonable" Level," Reuters, March 4, 2022, https://www.reuters.com/business/china-calls-rare-earths-companies-bring-prices-back-reasonable-level-2022-03-04/.

[279] Mary Hui, "Are High Rare Earth Prices Good for China?," Quartz, March 7, 2022, https://finance.yahoo.com/news/high-rare-earth-prices-good-220022712.html.

[280] Meeting between General Motors and the Department of Commerce, (Virtual Meeting, February 2, 2022).

[281] Mary Hui, "Are High Rare Earth Prices Good for China?," Quartz, March 7, 2022, https://finance.yahoo.com/news/high-rare-earth-prices-good-220022712.html.

[282] Meeting between Turntide Technologies and the Department of Commerce, (Virtual Meeting, February 17, 2022).

[283] Magnet material known as swarf is generated when magnet blocks are shaped to customer specifications.

[284] Meeting between the Critical Materials Institute and the Department of Commerce, (Virtual Meeting, October 6, 2021).

[285] "Adamas: cerium, lanthanum, terbium, and recycling can help fill the magnet rare earth gap," Green Car Congress, September 3, 2020, https://www.greencarcongress.com/2020/09/20200903-adamas.html; "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022,

significant academic research has been conducted on NdFeB magnet recycling and reuse technologies.[286] The research directly led to attempts at commercialization either through firms that manufacture end-use products (e.g., Nissan) or via specialized companies focused on the remanufacturing of sintered NdFeB magnets (e.g., Noveon). Increased demand for NdFeB magnets is likely to further pressure end-users to commercialize recycling technologies.

Separating NdFeB magnets from the products which house them is a major challenge of the recycling process. Firms that recycle magnets have limited visibility into the construction and design of products that use magnets, which makes disassembly difficult.[287] Continuing with the example of HDDs as a feedstock for NdFeB magnet recycling, the first difficulty in recycling HDDs is that most drives are shredded due to data sensitivities. Shredding reduces the ability to recover and recycle the NdFeB magnets and results in significant material loss.[288] Another option is manual removal, which recovers more material and has a lower environmental cost but is very time consuming.[289] In 2010, Hitachi announced that it had developed a machine to dismantle neodymium magnets from hard discs and compressors. The machine has a capacity of one hundred magnets per hour, about eight times faster than manual labor. The machine was supposed to be employed in commercial operations in 2013 but no follow up details are available.[290] One solution to the issue of separating magnets from end-of-life products is a labeling system to describe the specifications of contained NdFeB magnets, which would facilitate magnet recovery and the recycling process.[291]

The complexities involved in NdFeB magnet separation increase recycling costs. In 2014 a company approached by Japanese magnet manufacturers found they could not dismantle rare earth elements from HDDs at a profit.[292] That said, end-user firms in the United States and abroad have expressed interest in recycling magnets.[293] [294] This interest has helped to facilitate the commercialization of Noveon's magnet recycling and reengineering technology, [TEXT REDACTED].[295] More generally, increased demand for NdFeB magnets is likely to incentivize the commercialization of magnet recycling technologies.

In theory, NdFeB magnet reuse is possible without dismantling assemblies and remanufacturing contained magnets because magnets do not lose much strength over their lifetime. However,

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https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

[286] Recycling refers to deconstructing NdFeB magnets and reprocessing the contained rare earth elements. In contrast, reuse refers to integrating NdFeB magnets contained in end-of-life products into new products. As discussed later in this section, research and attempts at commercialization generally focus on recycling.

[287] Meeting between the Critical Materials Institute and the Department of Commerce, (Virtual Meeting, October 6, 2021).

[288] "Analysis of material efficiency aspects of personal computers product group," European Commission Joint Research Center, January 2018, http://dx.doi.org/10.2788/89220.

[289] Raymond Moss et al., "Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector: Assessing Rare Metals as Supply-Chain Bottlenecks in Low-Carbon Energy Technologies," European Commission Joint Research Center, 2013, https://publications.jrc.ec.europa.eu/repository/handle/JRC82322.

[290] Ibid.

[291] Meeting between the Critical Materials Institute and the Department of Commerce, (Virtual Meeting, October 6, 2021).

[292] Meeting between Hongyue Jin, Critical Materials Institute, and the Department of Commerce, (Virtual Meeting, October 22, 2021).

[293] Ibid.

[294] "Bentley sets out path to sustainable, recyclable electric motors," Automotive World, February 18, 2021, https://www.automotiveworld.com/news-releases/bentley-sets-out-path-to-sustainable-recyclable-electric-motors/.

[295] Meeting between Noveon and the Department of Commerce, (Virtual Meeting, November 12, 2021).

NdFeB magnets are often produced and shaped for a specific end-use product, and it is difficult to change the properties of the manufactured magnets, such that reuse is generally uncommon.[296]

Returning to the 2016 Rare Earths Assessment, 30 respondents indicated they recycled rare earth elements or rare earth element-related products, and 25 indicated they used recycled rare earth elements or rare earth element-related products. However, a number of these respondents do not operate in the NdFeB magnet value chain and their operations are unrelated to magnets. Other respondents explained that they sold material to be recycled or outsourced recycling operations, including to known magnet producers. [TEXT REDACTED] Some of the pessimistic responses reflect the contemporaneous state of technology. For example, [TEXT REDACTED]
The Department's survey of the U.S. NdFeB magnet industry presents a more encouraging picture of the potential contributions of recycled rare earths to the U.S. NdFeB magnet value chain. Survey participants included five current and potential recyclers: [TEXT REDACTED].[297]
[TEXT REDACTED]
[TEXT REDACTED]
In addition to these firms, in February 2022 the Critical Materials Institute (CMI) announced it had partnered with TdVib of Boone, IA, to commercialize rare earth element recycling.[298] In 2017, CMI first developed a novel NdFeB magnet recycling process to recover rare earth elements that dissolved magnets in an acid-free solution.[299] CMI's method can handle shredded electronic waste like HDDs and obviates the need to pre-process – for example, sort – the NdFeB magnets.[300] Being acid-free, CMI's technology is also more environmentally friendly than acid-based recycling processes.[301] TdVib has licensed this technology and intends to produce three to five tons of rare earth oxides in the next one to two years as part of the method's eventual commercialization.[302] The Small Business Innovation Research Program awarded TdVib Small Business Technology Transfer funding for this partnership, $200,000 in Phase I and $1.1 million in Phase II.[303]

8.4.2 NdFeB Magnet Substitutes

NdFeB magnet substitution can occur through several paths.[304] One NdFeB magnet input, such as dysprosium, could be substituted with another input, such as terbium. Alternatively, NdFeB magnets can be redesigned to reduce the content of certain inputs. As discussed in more detail below, some end-users are developing methods to decrease the quantity of heavy rare earth elements due to their high cost and concentrated supply chains. Products that rely on NdFeB magnets can also be redesigned to require NdFeB magnets with different characteristics. Finally,

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[296] Raymond Moss et al., "Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector: Assessing Rare Metals as Supply-Chain Bottlenecks in Low-Carbon Energy Technologies," European Commission Joint Research Center, 2013, https://publications.jrc.ec.europa.eu/repository/handle/JRC82322.
[297] [TEXT REDACTED].
[298] "Green rare-earth recycling goes commercial in the US," Ames Laboratory, February 25, 2022, https://www.ameslab.gov/index.php/news/green-rare-earth-recycling-goes-commercial-in-the-us.
[299] "Critical Materials Institute develops new acid-free magnet recycling process," Ames Laboratory, September 5, 2017, https://www.ameslab.gov/news/critical-materials-institute-develops-new-acid-free-magnet-recycling-process.
[300] Ibid.
[301] "Green rare-earth recycling goes commercial in the US," Ames Laboratory, February 25, 2022, https://www.ameslab.gov/index.php/news/green-rare-earth-recycling-goes-commercial-in-the-us.
[302] Ibid.
[303] "TdVib LLC," SBIR, n.d., https://www.sbir.gov/node/1653561.
[304] This paragraph draws on the DoE's "Rare Earth Permanent Magnets" report. "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

NdFeB magnets themselves can be replaced with alternative technologies. This could either be in the form of another type of magnet or by eliminating the need for magnets.

Background and Status of NdFeB Magnet Substitution

The U.S. Government has provided valuable funding for research on NdFeB magnet substitutes. In 2011, the Advanced Research Projects Agency – Energy (ARPA-E) funded 14 projects aimed at developing replacements for rare earth elements in electric vehicles and wind turbines through its Rare Earth Alternatives in Critical Technologies (REACT) Program.[305] These projects included research into cerium-based magnets, iron-nitride alloy magnets, manganese-aluminum based magnets, iron-nickel-based magnets, and carbon-based magnets, as well as rare earths-free applications like superconducting wire.[306] Although none of these alternatives have resulted in a mainstream alternative to NdFeB magnets, there have been some initial steps towards commercialization.[307] For example, the Critical Materials Institute is partnering with bonded NdFeB magnet producer Bunting Magnetics to test and conduct a feasibility study for cerium-based magnets.[308] This research has also been applied to end-products. For example, GE Renewables is planning to produce a prototype of a wind turbine generator using superconducting wire instead of NdFeB magnets in mid-2023.[309] In other cases such as carbon-based magnets, academic research has continued with little commercial success.[310]

In 2020, the Defense Advanced Research Projects Agency's Basic Energy Sciences division awarded a total of $20 million to five projects dealing with rare earth extraction.[311] Another $30 million was awarded in August 2021 to 13 projects focused on the "isolation of critical elements from natural and recycled resources" and which may reduce or eliminate the use of critical elements without functionality losses.[312] Although it is too early to tell whether these projects will lead to commercial products, the U.S. Government's continued support for research that may reduce dependence on rare earths and enhance supply chain resiliency is critical.

The private sector has also actively pursued substitution research. Turntide Technologies manufactures motors using switch reluctance motors that do not use NdFeB magnets.[313] [TEXT

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305 "Rare Earth Alternatives in Critical Magnets," Advanced Research Projects Agency – Energy, n.d., https://arpa-e.energy.gov/technologies/programs/react.

306 "REACT Program Overview," Advanced Research Projects Agency – Energy, n.d., https://arpa-e.energy.gov/sites/default/files/documents/files/REACT_ProgramOverview.pdf.

307 Research on iron-nitride magnets was spun-out to a private enterprise called Niron Magnetics, which is discussed later in this report and in Appendix G, "NdFeB Magnet Substitutes: Niron Magnetics."

308 "Commercialization of Cerium-based gap magnets – TCF award," Ames Laboratory, October 4, 2021, https://www.ameslab.gov/cmi/research-highlights/commercialization-of-cerium-based-gap-magnets-tcf-award.

309 Brett Nelson, "How Cool is This: Superconducting Generators Aim to Unlock More Offshore Wind Power at Lower Cost," GE Renewables, February 24, 2021, https://www.ge.com/news/reports/how-cool-is-this-superconducting-generators-aim-to-unlock-more-offshore-wind-power-at-lower.

310 "Revolutionary Carbon-Based Magnetic Material Finally Synthesized After 70 Years," SciTech Daily, January 28, 2022, https://scitechdaily.com/revolutionary-carbon-based-magnetic-material-finally-synthesized-after-70-years/.

311 "DOE Awards $20 Million for Research on Rare Earth Elements," Department of Energy, August 25, 2020, https://www.energy.gov/articles/doe-awards-20-million-research-rare-earth-elements.

312 "Critical Minerals and Materials: Chemical and Materials Sciences Research on Rare Earth and Platinum Group Elements," Department of Energy, https://science.osti.gov/-/media/bes/pdf/Funding/2021/FY2021_CM_Awards.pdf?la=en&hash=D76330B7A090B12B63F0EB2AB83DD43FB367D61C.

313 Meeting between Turntide Technologies and the Department of Commerce, (Virtual Meeting, February 17, 2022).

REDACTED].[314] Among automobile manufacturers, Toyota has been working to develop NdFeB magnet substitutes for over a decade. In 2011, Toyota announced that it was researching rare earth-free motors.[315] In 2018, Toyota announced that it had produced a preliminary design for a magnet that partially replaced neodymium with lanthanum and cerium, reducing total neodymium content in the magnet by 20 to 50 percent.[316] In 2022, Toyota's subsidiary Denso announced that it is developing rare earths-free iron-nickel magnets, although it did not give a timeline for commercialization.[317] In 2016, Honda also announced it would use a heavy rare earth element-free motor in some hybrid electric vehicles.[318] Other automobile manufacturers, including BMW, Daimler, Nissan, and Volkswagen, are researching methods to reduce the amount of rare earth elements used in NdFeB magnets.[319] For example, the German firm Mahle announced rare earths-free motors for vehicle applications, with mass production to commence around 2024.[320]

Example: NdFeB Magnet Substitution Using Iron-Nitride Magnets
Iron-nitride magnets are a potential NdFeB magnet substitute with several attractive qualities.[321] Iron-nitride magnets are made of iron and nitrogen powder. [TEXT REDACTED].[322] [TEXT REDACTED].[323] [TEXT REDACTED].[324] [TEXT REDACTED].[325]

Although iron-nitride has been known for many years, it has yet to be commercialized because of the difficulties involved in manufacturing.[326] Researchers at the University of Minnesota, funded by ARPA-E's REACT program, were the first to produce an iron-nitride magnet prototype. This research was spun out into a commercial venture called Niron Magnetics. Niron Magnetics continues to develop this technology [TEXT REDACTED].[327] [TEXT REDACTED].[328] [TEXT REDACTED].[329]

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314 Ibid.
315 Nikki Gordon-Bloomfield, "Toyota Seeks to Ditch Rare Earth Metals from Electric Motors, Green Car Reports, January 17, 2011, https://www.greencarreports.com/news/1053778_toyota-seeks-to-ditch-rare-earth-metals-from-electric-motors.
316 Megan Geuss, "Toyota's new magnet won't depend on some key rare-earth minerals," ArsTechnica, February 28, 2018, https://arstechnica.com/cars/2018/02/neodymium-more-like-neo-dont-mium-new-magnet-uses-fewer-key-rare-earths/.
317 "High-performance magnet that does not use rare earths," Chunichi Shimbun, January 8, 2022, https://www.chunichi.co.jp/article/394835.
318 Lindsay Brooke, "Honda's new e-motor magnet aims to mitigate China rare-earth monopoly," SAE International, July 17, 2016, https://www.sae.org/news/2016/07/hondas-new-e-motor-magnet-aims-to-mitigate-china-rare-earth-monopoly.
319 "Factbox: Automakers Cutting Back on Rare Earth Magnets," Reuters, July 19, 2021, https://www.reuters.com/business/autos-transportation/automakers-cutting-back-rare-earth-magnets-2021-07-19/; Claudiu C. Pavel et al., "Role of substitution in mitigating the supply pressure of rare earths in electric road transport applications," Sustainable Materials and Technologies (12): 62-72, July 2017, https://doi.org/10.1016/j.susmat.2017.01.003.
320 Philip E. Ross, "In Mahle's Contact-Free Electric Motor, Power Reaches the Rotor Wirelessly," IEEE Spectrum, May 12, 2021, https://spectrum.ieee.org/mahles-electric-motor-says-look-ma-no-contacts.
321 [TEXT REDACTED].
322 Meeting between Niron Magnetics and the Department of Commerce, (Virtual Meeting, January 7, 2022).
323 Ibid.
324 "Niron Magnetics: Summary of Environmental Life Cycle Analysis," Niron Magnetics, November 25, 2021.
325 Meeting between Niron Magnetics and the Department of Commerce, (Virtual Meeting, January 7, 2022).
326 Ibid.
327 Ibid.
328 Ibid.
329 Ibid.

Example: NdFeB Magnet Substitution Using Nanotechnology

Sintered NdFeB magnets used in critical infrastructure and high growth applications, such as electric vehicles and offshore wind turbines, require elevated temperature properties that necessitate the addition of heavy rare earths like dysprosium and terbium. Heavy rare earth deposits are even more concentrated in China than neodymium and, after recent Chinese industry consolidation, a single state-owned enterprise – China Rare Earth Group – will control most capacity.[330] [331] Although USA Rare Earth's Round Top Mine in Texas is expected to produce dysprosium, China will continue to dominate global production.[332]

MQ3 magnets, first developed by General Motors in 1985 and later commercialized by Magnequench in 1987, are a type of NdFeB magnet that may offer a reduced heavy rare earth element or heavy rare earth element-free alternative to sintered NdFeB magnets.[333] [334] With the exception of a reduced need for heavy rare earth elements, MQ3 magnets rely on similar feedstocks as sintered and bonded NdFeB magnets. However, MQ3 magnets are manufactured using different methods that affect their heavy rare earth element requirements. MQ3 magnets rely on thermomechanical processes to produce dense anisotropic microstructures that enable the development of high energy products required for elevated temperature applications like electric vehicles.[335] The production of MQ3 magnets involves the following steps: 1) rapid solidification of feedstock into ribbon and then milling into powder (also used for bonded NdFeB magnets), 2) hot deformation of powder into fully dense isotropic magnets through hot pressing, hot extrusion, or spark plasma sintering (called MQ2), and 3) die-upsetting or back extrusion to form fully dense anisotropic magnets (called MQ3).[336] MQ3 magnets can be made with very high energy density. In the 1990s, researchers reported energy products in MQ3 magnets comparable to high energy sintered NdFeB magnets.[337] [338] MQ3 magnets can possess similar characteristics as sintered NdFeB magnets, despite their different manufacturing processes.

While comparable in performance metrics to sintered NdFeB magnets, MQ3 magnets use a smaller amount of heavy rare earth elements due to microstructural differences. As the grain size of NdFeB magnets' microstructure is reduced, the magnets' resulting coercivity increases due to higher domain wall pinning.[339] MQ3 magnets' thermomechanical manufacturing process means that their grain sizes are in the range of 20 to one hundred nanometers, orders of magnitude smaller than the five to ten micrometers in a typical sintered NdFeB magnet.[340] MQ3 magnets

[330] Meeting between USA Rare Earth and the Department of Commerce, (Virtual Meeting, December 10, 2021).
[331] Sun Yu and Tom Mitchell, "China Merges 3 Rare Earth Miners to Strengthen Dominance of Sector," Financial Times, December 23, 2021, https://www.ft.com/content/4dc538e8-c53e-41df-82e3-b70a1c5bae0c.
[332] Meeting between USA Rare Earth and the Department of Commerce, (Virtual Meeting, December 10, 2021).
[333] R. W. Lee, "Hot-pressed neodymium-iron-boron magnets," Applied Physics Letters 46: 790, 1985, https://doi.org/10.1063/1.95884.
[334] V. Panchanathan, "Magnequench Magnets Status Overview," Journal of Materials Engineering and Performance, 4 (4) 423-429, 1995, https://doi.org/10.1007/BF02649302.
[335] Ibid.
[336] Ibid.
[337] C. D. Fuerst and E. G. Brewer, "High-remanence rapidly solidified Nd-Fe-B: Die-upset magnets," Journal of Applied Physics 73: 5751, 1993, https://doi.org/10.1063/1.353563.
[338] V. Panchanathan, "Magnequench Magnets Status Overview," Journal of Materials Engineering and Performance, 4 (4) 423-429, 1995, https://doi.org/10.1007/BF02649302.
[339] J. F. Herbst, "$R_2Fe_{14}B$ materials: Intrinsic properties and technological aspects," Reviews of Modern Physics, 63 (4): 819-898, 1991, https://doi.org/10.1103/RevModPhys.63.819.
[340] Ibid.

thus display higher coercivity, including at elevated temperatures. As a result of these properties, MQ3 magnets require less heavy rare earth elements than sintered NdFeB magnets.[341] [342]

Extant research indicates that substituting MQ3 magnets for sintered NdFeB magnets could substantially reduce or even eliminate the use of heavy rare earth elements. In one study comparing equivalent MQ3 and sintered NdFeB magnets, dysprosium-free MQ3 magnets were equivalent to sintered NdFeB magnets with 3.43 percent dysprosium by weight.[343] Although MQ3 magnets needed to be four percent dysprosium by weight to be equivalent to a sintered NdFeB magnet composed of 6.45 percent dysprosium by weight, this still represents a considerable reduction in heavy rare earth element content.[344] In another study comparing MQ3 and sintered NdFeB magnets with similar temperature coercivities at 180 degrees, the MQ3 magnets required four percent less dysprosium by weight than their sintered NdFeB magnet counterparts.[345] Future research could further optimize the microstructure, reduce grain sizes to exhibit single domain behavior, and maximize pinning dominated demagnetization, which may enhance coercivity and result in even greater reductions in heavy rare earth element content.

Although the method to produce MQ3 magnets was first discovered in 1985, the current NdFeB magnet industry primarily produces bonded and especially sintered NdFeB magnets. One major reason for this equilibrium is that the processing costs for MQ3 magnets are higher than for sintered NdFeB magnets.[346] However, the rise in heavy rare earth prices has increased the proportion of magnet costs attributable to feedstock prices and may make MQ3 magnets more economically competitive. That said, MQ3 magnets were never fully decommercialized. There are currently at least two firms that produce MQ3 magnets: Neo Performance Materials of Canada and Magnet e Motion of the Netherlands.[347] [348] In addition to these magnet manufacturers, Honda appears to have commercialized the use of MQ3 magnets.[349] In July 2016, Honda and Daido Steel announced the use of MQ3 magnets in one of its hybrid electric traction drive motors, with production to commence in August 2016.[350] Daido Steel planned to use feedstock from Neo Performance Materials' predecessor Magnequench International to produce the magnets at a facility in Japan.[351] [TEXT REDACTED]

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[341] "Automotive," Neo Magnequench, n.d., https://mqitechnology.com/applications/automotive/.
[342] "Radially oriented, anisotropic Nd-Fe-B ring magnets (NEOQUENCH-DR)," Daido Electronics, n.d., http://daido-electronics.co.jp/english/product/neoquench_dr/index.html?msclkid=a3ef65e0cbb811ecb84db59d0093c2de.
[343] Steve Constantinides, "Manufacture of Modern Permanent Magnet Materials," Arnold Magnetic Technologies, n.d., https://www.arnoldmagnetics.com/wp-content/uploads/2017/10/Manufacture-of-Modern-Permanent-Magnet-Materials-Constantinides-PowderMet-2014-ppr.pdf.
[344] Ibid.
[345] John Ormerod, "MQ3 Fully Dense NdFeB Magnets," Bunting, n.d., https://bunting-dubois.com/tech-briefs/types-of-rare-earth-magnets-part-3/.
[346] David Brown, Bao-Min Ma, and Zhongmin Chen, "Developments in the processing and properties of NdFeb-type permanent magnets," Journal of Magnetism and Magnetic Materials, 248 (3): 432-440, 2002, https://doi.org/10.1016/S0304-8853(02)00334-7.
[347] "Products," Neo Magnequench, n.d., https://mqitechnology.com/products/.
[348] "Hot Formed NdFeB Magnets (MQ3)," Magnet e Motion, n.d., https://magnetemotion.com/technology-mq3-ndfeb-extrusion.html.
[349] "Daido Steel and Honda develop neodymium magnet free of heavy rare earth elements; Honda Freed hybrid first to adopt resulting new motor," Green Car Congress, July 12, 2016, https://www.greencarcongress.com/2016/07/20160712-honda.html.
[350] Ibid.
[351] Ibid.

In summary, there are two different approaches which can be used to improve coercivity and resulting resistance to demagnetization at elevated temperature, one of which – MQ3 magnets – is less reliant on heavy rare earth elements. In sintered NdFeB magnets, heavy rare earths such as terbium and dysprosium are added which results in higher feedstock costs and an even greater reliance on Chinese supply chains. MQ3 magnets' smaller grain size enables manufacturers to reduce or eliminate heavy rare earth elements while maintaining comparable performance. Although MQ3 magnets' processing methods are more expensive than sintered NdFeB magnets', heavy rare earth element feedstock prices may make MQ3 magnets economically competitive. In addition, using less heavy rare earth elements would decrease dependence on China, which dominates global heavy rare earth element production even more than global light rare earth element production. MQ3 magnets are a potential substitute for sintered NdFeB magnets and would be particularly useful in reducing U.S. dependence on heavy rare earth elements.

Commercial Viability of NdFeB Magnet Substitutes

Despite advances, most substitution technologies are still at least several years away from commercialization, which means they will be unable to satisfy growing demand for NdFeB magnets from green technology (e.g., electric vehicles and wind turbines) over the same timeframe.[352] In addition, most substitutes currently being researched would require other rare earth elements (such as lanthanum) and would only replace lower-grade NdFeB magnets, meaning that NdFeB magnets would still be required in high heat application, including electric vehicle drive trains, or when efficiency is highly desired. Although other rare earth elements are cheaper, China dominates rare earth production. Any viable substitute would also have to quickly scale up production. The manufacture of different types of magnets is similar, so shifting a production facility from NdFeB magnets or samarium cobalt magnets to a substitute may be possible but would still require available facilities. Finally, because NdFeB magnets are highly tailored to end-user specifications, customers would have to make product adjustments to account for substitutes.[353] Substitution research has the potential to impact production in the long-term but requires present action to enable success.

The Department's survey of the U.S. NdFeB magnet industry provides support for the view that current substitutes are of limited commercial viability. The survey asked producers of assemblies or systems containing NdFeB magnets to indicate whether magnet substitutes were available for their primary products, and if so, to identify the potential substitute and discuss the advantages and disadvantages of the substitute. 21 firms indicated 57 products in response. [TEXT REDACTED].[354] [TEXT REDACTED] 14 firms indicated 38 products (67 percent) where no substitutes were available for NdFeB magnets.[355] [TEXT REDACTED], these were a mix of rotors and motors, in addition to speakers, wind turbines, and other products, to be used in 15 different industries.[356] For the vast majority of firms in our sample [TEXT REDACTED] substitutes were either unknown or unavailable for most products [TEXT REDACTED], and the only substitute listed was another rare earth magnet, speaking to the dearth of currently commercially viable NdFeB magnet substitutes.

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352 [TEXT REDACTED]
353 [TEXT REDACTED]
354 The NdFeB magnets in question were all sintered NdFeB magnets.
355 [TEXT REDACTED].
356 The industries cited included all [TEXT REDACTED] industries where the NdFeB magnets that could be substituted for [TEXT REDACTED] were destined to be used.

The relationship between NdFeB magnet component prices and NdFeB magnet imports further underscores the lack of commercially viable NdFeB magnet substitutes. If NdFeB magnet substitutes are commercially available, then end-users should be able to switch production to use NdFeB magnet substitutes. As a result, as NdFeB magnet prices rise demand should fall, and vice versa. To examine whether this is the case, the Department analyzed the relationship between neodymium oxide prices and NdFeB magnet imports. Neodymium oxide prices are a good proxy for NdFeB magnet prices because neodymium is the largest contributor to NdFeB magnet cost. NdFeB magnet imports are a relatively reliable indicator of direct demand because the United States is nearly one hundred percent dependent on imports.[357] The correlation between the daily price of neodymium oxide and the daily value of NdFeB magnet imports from 2016 to 2021 is 0.23, while the equivalent correlation for the daily quantity (units) of NdFeB magnet imports is 0.06. Neodymium oxides prices are thus somewhat positively associated with the value of NdFeB magnet imports, given that increases in the value of NdFeB magnet components should raise the value of NdFeB magnets. However, the correlation with the quantity of NdFeB magnet imports is very weak, suggesting that end-users do not change their importing behavior in response to increases in NdFeB magnet costs. The relatively weak correlation between the price of neodymium oxide and the quantity of NdFeB magnet imports lends further credence to the view that although other magnets or non-magnet components can substitute for NdFeB magnets in certain situations, wholesale substitution is currently not possible.

9. Conclusion

9.1 Findings

In this section the Department discusses the key findings from its investigation into the effects of imports of NdFeB magnets on U.S. national security. These findings are based on data collected from an industry survey, industry meetings, extant U.S. Government research, and other sources, as discussed in earlier sections.

9.1.1 NdFeB Magnets are Essential to U.S. National Security

NdFeB Magnets are Key Components of National Defense Systems

NdFeB magnets are critical to the functioning of numerous defense systems, including fighter aircraft and missile guidance systems. Although NdFeB magnets can sometimes be substituted for with alternative products, these products are usually not as effective and may reduce system performance. NdFeB magnets are therefore essential to U.S. national security.

NdFeB Magnets are Key Components of Critical Infrastructure

NdFeB magnets are used in a broad range of products across virtually all 16 critical infrastructure sectors. NdFeB magnets are necessary and largely non-substitutable components of goods in multiple critical infrastructure sectors. NdFeB magnets are particularly important for the critical manufacturing and critical energy sectors, as they are key to the functioning of electric vehicle drive trains and offshore wind turbine generators. They also have an important role in the critical healthcare and public health sector, where they are used in MRI machines and other medical instruments, and the critical defense industrial base sector.

[357] The Department acknowledges that there is significant indirect demand for NdFeB magnets.

The Department previously determined that "national security" can be interpreted to include the general security and welfare of certain "critical industries."[358] The Department currently uses the 16 critical infrastructure sectors identified in Presidential Policy Directive 21 to define critical industries.[359] NdFeB magnets are therefore also essential to U.S. national security by virtue of their indispensable use in critical infrastructure sectors. NdFeB magnets' criticality is heightened by the fact they are key components of electric vehicles and offshore wind turbines. These products are central to achieving the United States' clean energy goals and combating climate change, which have important national security implications.[360]

9.1.2 Domestic Demand for NdFeB Magnets is Expected to Grow

Total U.S. – and global – demand for NdFeB magnets is expected to grow significantly in the coming decades, driven by increased production of electric vehicles and offshore wind turbines. Under high growth scenarios, total domestic demand is expected to more than double from 2020 to 2030, growing from just over 16,000 tons to 37,000 tons, and more than quadruple from 2020 to 2050, increasing to almost 69,000 tons.[361] Total global demand is forecasted to grow even more quickly, tripling from 2020 to 2030 from 119,000 tons to 387,000 tons and increasing sixfold from 2020 to 2050 to over 750,000 tons. Domestically, electric vehicles will consume more than 10,000 tons by 2030 and 23,000 tons by 2050, up from just under 2,000 tons in 2020. Domestic offshore wind turbine-driven demand will increase from zero in 2020 to over 10,000 tons in 2030 and 19,000 tons in 2050. Together, these critical infrastructure products will make up almost 55 percent of total U.S. demand in 2030 and over 61 percent of total U.S. demand by 2050, up from 11 percent in 2020. Total domestic demand from traditional end-users is also expected to grow, albeit at a slower rate.

A key outstanding question is the extent to which firms will locate the production of assemblies that integrate NdFeB magnets, such as electric vehicle motors and wind turbine generators, in the United States. If firms elect to produce products containing NdFeB magnets overseas this will increase embedded U.S. demand for NdFeB magnets but not affect direct U.S. demand or contribute to a domestic market for NdFeB magnets. U.S. NdFeB magnet value chain participants are more likely to successfully establish and maintain production if they are proximate to their customers, due to transportation costs and turn times.[362] In addition, even end-users that manufacture domestically may be unwilling to pay a premium for domestic or ally magnets over Chinese magnets. Onshoring or nearshoring of end-user industries and incentivizing the use of domestic NdFeB magnets will be critical to the success of the U.S. NdFeB magnet industry.

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[358] "The Effects of Imports of Iron Ore and Semi-Finished Steel on the National Security," Department of Commerce, Bureau of Export Administration, October 2001 ("2001 Iron and Steel Report"), at 5, https://www.bis.doc.gov/index.php/documents/steel/2224-the-effect-of-imports-of-steel-on-the-national-security-with-redactions-20180111/file.

[359] Presidential Policy Directive 21, "Critical Infrastructure Security and Resilience," February 12, 2013.

[360] David Vergun, "Climate Change Has National Security Implications, DOD Official Says," Department of Defense, https://www.defense.gov/News/News-Stories/Article/Article/2707739/climate-change-has-national-security-implications-dod-official-says/.

[361] This section uses demand data from the DoE's "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report." *See* "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

[362] Meeting between Lynas Rare Earths and the Department of Commerce, (Virtual Meeting, March 30, 2022); Meeting between Quadrant Magnetics and the Department of Commerce, (Virtual Meeting, February 15, 2022).

The substantial growth in total U.S. demand will increase U.S. dependence on imports of NdFeB magnets without the rapid development of a competitive U.S. NdFeB magnet industry. However, it also presents an opportunity to facilitate the formation of just such an industry. If a large enough proportion of the products that directly incorporate NdFeB magnets – such as electric vehicle drive trains – are manufactured in the United States and the price differential between U.S. and Chinese magnets can be sufficiently narrowed, domestic NdFeB magnet producers may benefit from a sizeable and stable source of demand.

9.1.3 The United States and its Allies are Dependent on Imports from China

The United States is currently one hundred percent dependent on imports of sintered NdFeB magnets and is highly dependent on imports of bonded NdFeB magnets. The United States does not currently possess the capacity to manufacture sintered NdFeB magnets and only makes a small amount of bonded NdFeB magnets. In addition, the United States does not produce rare earth oxides, NdFeB-related metals, or NdFeB alloys, such that current bonded NdFeB magnet manufacturers are dependent on imported feedstocks. The majority of direct U.S. NdFeB magnet demand is satisfied by imports from China. In 2021, China accounted for 75 percent of U.S. sintered NdFeB magnet imports by value, up from under 60 percent in 2016. Given substantial indirect demand, this may even underestimate the United States' overall dependence on China for NdFeB magnets. For example, up to 60 percent of essential civilian demand is satisfied through embedded imports.[363]

U.S. allies are also dependent to varying degrees on China. Although the European Union and Japan operate in the downstream steps of the NdFeB magnet value chain, they are dependent on China for feedstock to produce metals, alloys, and magnets. Other U.S. allies, such as Australia, only operate in the upstream portions of the NdFeB magnet value chain. More broadly, China can shape global prices due to its dominance in all value chain steps and the increasing concentration of its domestic industry.

9.1.4 The United States Will Continue to Depend on Imports

Multiple firms intend to establish domestic capacity at different steps of the NdFeB magnet value chain. If successful, these plans have the potential to create a U.S. NdFeB magnet value chain from mine to magnet and would reduce – but far from eliminate – import dependence on China. Based on its survey of the U.S. NdFeB magnet industry, the Department estimates that the United States could produce more than 14,000 tons of sintered NdFeB magnets by 2026. Should all these magnets be consumed domestically, import penetration may decline from one hundred percent in 2021 to as low as 49 percent in 2026.[364] Despite this potentially significant decline in import penetration, U.S. production would likely struggle to fulfill critical infrastructure demand. Assuming linear growth from 2020 to 2030, combined domestic NdFeB magnet demand from the automobile and wind energy sectors will be almost 15,000 tons in 2026, exceeding domestic production.[365] In addition, domestic NdFeB magnet manufacturing will be constrained by

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[363] "Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth," The White House, June 2021, https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf.
[364] For further information on the assumptions and data used to reach these figures, *see* Section 8.1.4, "Estimated NdFeB Magnet Import Penetration, 2017 to 2026."
[365] This figure combines estimates of total U.S. demand for electric vehicles, offshore wind turbines, and non-electric vehicle drive trains, [TEXT REDACTED]. For the demand estimates *see* "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022,

domestic production of rare earth metals and NdFeB alloys. The Department estimates the U.S. NdFeB magnet industry will produce [TEXT REDACTED] of NdFeB alloy by 2026, enough for between [TEXT REDACTED] of NdFeB magnets, far less than overall and critical infrastructure demand.[366] Despite diverse efforts to establish a U.S. NdFeB magnet industry, the United States will continue to depend on imports of NdFeB magnets and related feedstock to fulfill demand, including from critical infrastructure sectors.

9.1.5 The U.S. NdFeB Magnet Industry Faces Significant Challenges

The nascent U.S. NdFeB magnet industry faces significant barriers to achieve its production targets. In particular, the U.S. NdFeB magnet industry participants will need to compete with Chinese manufacturers, who benefit from favorable tax and tariff policies, low labor and energy costs, and comparatively relaxed environmental regulations, among other factors. Indeed, U.S. producers consistently cite foreign competition as a top challenge to their competitive position. Chinese competition is also often mediated by other major challenges such as labor costs and input availability.

In addition to Chinese competition, U.S. firms face financial and human capital constraints. NdFeB magnet facilities – and facilities at earlier value chain steps – are expensive, and U.S. firms have currently allocated almost no funds to establish planned facilities. For example, sintered NdFeB magnet facilities cost on average [TEXT REDACTED], but firms have on average allocated less than [TEXT REDACTED] for each facility. Further, the collapse of the U.S. NdFeB magnet industry in the 1990s means that planned U.S. NdFeB magnet producers struggle to find qualified and experienced workers, especially high wage employees such as materials scientists.

Finally, there is high uncertainty over demand for U.S. NdFeB magnets. Not only do a significant portion of end-users manufacture products overseas, but even domestic manufacturers may prefer to continue using less expensive Chinese NdFeB magnets. Ensuring that enough end-users integrate magnets into intermediate and final products in the United States will be crucial for the success of the U.S. NdFeB magnet industry. Planned U.S. NdFeB magnet industry participants may struggle to achieve production estimates, given these and other obstacles.

9.2 Determination

Based on the findings in this report, the Secretary concludes that the present quantities and circumstances of NdFeB magnet imports threaten to impair the national security as defined in section 232 of Trade Expansion Act of 1962, as amended.

9.3 The United States Should Not Restrict NdFeB Magnet Imports

Despite the heavy dependence of the United States on direct and indirect imports of NdFeB magnets, the Department currently recommends that the Administration not impose tariffs, quotas, or other import restrictions on NdFeB magnets or component products. Given the current severe lack of domestic production capability throughout the magnet supply chain, tariffs and quotas would have an adverse impact on consuming sectors and might incentivize businesses to move operations incorporating NdFeB magnets offshore. In both industry meetings and public

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https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

[366] *See* Section 5.2, "Rare Earth Element Losses in Magnet Production," for estimates of material loss from alloy production to magnet production.

comments, most representatives of consuming sectors oppose the imposition of trade restrictions for these reasons. As Dana, a manufacturer of electric motors, stated, tariffs "would potentially curtail any future plans to bring parts of its electric motor manufacturing to the U.S."[367] Even planned magnet manufacturers, such as MP Materials, emphasize that tariffs could incentivize substitution or offshoring, although they do not discount the ability of tariffs or quotas to aid an established NdFeB magnet manufacturing sector. The U.S. Government may reconsider the merits of imposing tariffs or other import restrictions, based on section 232 of the Trade Expansion Act of 1962, as amended, or other policy levers, as the domestic supply chain develops production capacity.

9.4 Recommendations

The Department has identified several actions that would help to ensure reliable domestic sources of NdFeB magnets and lessen the risk that imports threaten the national security. These actions are not intended to be exhaustive or exclusive, and the Secretary recommends that the Administration pursue all proposed actions.

9.4.1 Engagement with Allies and Partners

U.S. Ally Vulnerabilities

The national security of U.S. allies and partners is essential to U.S. national security, and both are undermined by allies' and partners' reliance on China with respect to the NdFeB magnet value chain. Australia relies on China to buy rare earth materials, while both Japan and the European Union rely on China to purchase rare earth oxides and metals to make NdFeB magnets. There is also broad reliance by U.S. allies on China for NdFeB magnets – [TEXT REDACTED].[368] Such reliance leaves allies open to supply chain disruptions or potential economic coercion by China. For example, China has previously restricted its imports of Australian coal and its exports of rare earths to Japan. China's export restrictions to Japan in 2010, while only lasting two months, caused supply chain problems for Japanese firms and galvanized Japan into diversifying its supply of rare earths.[369]

Multilateral Engagement on Critical Minerals

Shared vulnerabilities highlight the value of current multilateral – as well as bilateral – engagements on critical minerals, which can help transition the United States and allies from reliance on a potential adversary and national security threat. Continued multilateral engagement through existing fora, such as the Conference on Critical Materials and Minerals, in concert with current bilateral engagements, including with Australia, Canada, and the European Union, will facilitate efficient coordination on supply chain resiliency issues across the full NdFeB magnet value chain. The United States should work with allies through these existing engagements to develop production at different steps of the value chain, encourage intellectual property licensing, and cooperate on foreign investment reviews, in addition to other actions.

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[367] Comments of Dana to Request for Public Comments, "Section 232 National Security Investigation of Imports of Neodymium-Iron-Boron (NdFeB) Permanent Magnets," 86 FR 53277, November 12, 2021.

[368] [TEXT REDACTED]. *See* Adamas Intelligence, "Rare Earth Magnet Market Outlook to 2030," 2020; "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

[369] Restrictions to Japan were first reported in September 2010 and were lifted two months later in November 2010. Kristen Vekasi, "Politics, markets, and rare commodities: Responses to Chinese rare earth policy," Japanese Journal of Political Science 20 (1): 2-20, 2019, https://doi.org/10.1017/S1468109918000385; "China resumes rare earth exports to Japan," BBC, November 24, 2010, https://www.bbc.com/news/business-11826870.

The United States and allies should leverage burgeoning multilateral mechanisms to enhance focus on identifying the most cost-effective deposits, prioritizing the most commercially viable ones, and then pooling funding for production. The United States has one of the highest-grade deposits of rare earth elements in the world at Mountain Pass Mine in California. Round Top Mine in Texas, scheduled to begin production in 2023, may become a viable source of dysprosium. Meanwhile, Australia has some of the richest deposits of uranium and gallium, along with significant rare earth elements. Leveraging assets and comparative advantage amongst allies and partners will help develop a critical minerals supply chain in economically viable locations in a manner consistent with the United States' labor, environmental, equity, and other values.

In addition to funding market development, multilateral action should address technology sharing. While not cited as a critical barrier to entry, NdFeB magnet industry participants indicate intellectual property licensing would facilitate production. Industry participants are also researching NdFeB magnet substitutes and methods to reduce rare earths content that would increase supply chain resiliency, the commercialization of which should be promoted. Intellectual property licensing to firms from ally and partner countries should be encouraged and facilitated, especially when it reduces reliance on sourcing from non-allies. Allies and partners should reciprocate and respect all intellectual property. Emphasis should be placed on sharing technology that reduces the negative impacts of mining or separation, improves the extraction of rare earth elements from unconventional sources, fosters novel and effective recycling technologies, and develops effective magnet substitutes.

Coordinating foreign investment review mechanisms, which affect how quickly international capital can flow to priority facilities, should also be part of multilateral engagements. U.S. foreign investment law has exceptions for investors from certain countries, including important NdFeB magnet value chain participants such as Australia and Canada.[370] Those exceptions facilitate investments between the United States and its allies; other countries should be encouraged to reciprocate for U.S.-origin investments. Coordinating inbound investment review regimes may also help protect against the risk that an untrusted investor gains access to an important piece of the supply chain by investing in a trusted country. Outbound investment controls, similar to the ones currently before Congress, may reduce the risk that a firm based in an allied country will sell key assets located overseas to a foreign adversary.[371] The Australian firm Peak Rare Earths is an example of how foreign investment controls could be used to monitor and reduce risk in the NdFeB magnet supply chain. Peak Rare Earths is a potentially important non-Chinese rare earths market participant. As discussed in Appendix E, "Global NdFeB Magnet Production: A Firm-level Perspective," a Chinese firm recently took a significant stake in Peak Rare Earths in an inbound transaction to Australia. Outbound review could protect against the risk of Peak Rare Earths' Chinese investors compelling it to sell critical facilities to Chinese owners, whether those facilities are in allied countries (such as its planned rare earth

[370] "CFIUS Exempted Foreign States," U.S. Department of the Treasury, https://home.treasury.gov/policy-issues/international/the-committee-on-foreign-investment-in-the-united-states-cfius/cfius-excepted-foreign-states.
[371] "Text – H.R. 5421- United States Innovation and Competition Act," U.S. House of Representatives, February 4, 2022, https://www.congress.gov/bill/117th-congress/house-bill/4521/text/eh (Section 104001).

oxide separation facility in the United Kingdom) or elsewhere (such as its Ngualla mining project in Tanzania).[372]

There are several established and relevant fora which can serve as venues for structured engagement with allies on these and other issues related to NdFeB magnets. For example, the Conference on Critical Materials and Minerals, which brings together Australia, Canada, the European Union, Japan, and the United States, is an important venue to regularly exchange information on policies for critical materials, research and development, and other efforts, and could be the site of further multilateral engagement.[373] In March 2022, the International Energy Agency announced a voluntary critical materials security program that could be another forum to coordinate on issues related to NdFeB magnets.[374] In addition to these multilateral fora, the Japan-U.S. Industrial Cooperation Partnership, the U.S.-Australia Action Plan, U.S.-Brazil Critical Minerals Working Group, the U.S.-Canada Action Plan, and the U.S.-E.U. Trade and Technology Council are all important bilateral venues in which the United States could engage in structured dialogue and coordination with allies on NdFeB magnet-related supply chain resiliency issues.

9.4.2 Bolster Domestic Supply

Establish Rare Earths Tax Credits

The Department recommends that the Administration support the passage of H.R. 5033, the Rare Earth Magnet Manufacturing Production Tax Credit Act, or similar legislation.[375] This bipartisan legislation would establish a $20 per kilogram tax credit for rare earth magnets manufactured in the United States, and an enhanced $30 per kilogram credit for magnets manufactured in the United States for which all the component materials are produced domestically. This legislation covers both NdFeB magnets and samarium-cobalt magnets. In both the public comments and in industry meetings, NdFeB magnet producers and value chain participants expressed support for this legislation. Although they did not cite this legislation directly, end-users indicated support for domestic manufacturing incentives as opposed to tariffs. H.R. 5033 or similar legislation would increase the cost competitiveness of U.S. NdFeB magnets and magnet feedstocks relative to their Chinese counterparts and galvanize the development of a U.S. NdFeB magnet value chain. A tax credit should include magnets produced by or using materials from U.S. allies.

In addition to a tax credit for NdFeB magnets, the Department recommends that the Administration support the development of tax credits for non-NdFeB magnets that can substitute for NdFeB magnets and upstream rare earth products including carbonates, oxides, metals, and alloys. NdFeB magnet substitute and upstream rare earth product tax credits would similarly improve cost competitiveness and facilitate the growth of U.S.-produced magnetic materials. As with a rare earth tax credit, any NdFeB magnet substitute and upstream rare earth product tax credits should include materials produced by U.S. allies.

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[372] Note that Shenghe Resources, the Chinese investor in Peak Rare Earths, also purchased eight percent of U.S. mining firm MP Materials. *See* Mary Hui, "A Chinese rare earths giant is building international alliances worldwide," Quartz, February 19, 2021, https://qz.com/1971108/chinese-rare-earths-giant-shenghe-is-building-global-alliances/.

[373] For additional information on the Conference on Critical Materials and Minerals, *see* "12th Conference on Critical Materials and Minerals Held," Ministry of Economy, Trade, and Industry, December 9, 2021, https://www.meti.go.jp/english/press/2021/1209_002.html.

[374] *See* "2022 IEA Ministerial Communiqué," International Energy Agency, March 24, 2022, https://www.iea.org/news/2022-iea-ministerial-communique.

[375] *See* "H.R. 5033 – Rare Earth Magnet Manufacturing Production Tax Credit Act of 2021," Congress.gov, n.d., https://www.congress.gov/bill/117th-congress/house-bill/5033.

Defense Production Act Title III Funding
As discussed earlier, the Department of Defense (DoD) has made several notable awards through the Defense Production Act (DPA) Title III program to firms in the NdFeB magnet value chain. These awards have largely focused on the development of oxide separation and sintered NdFeB magnet production facilities. Further DoD awards for alloying and metallization production could facilitate the development of a holistic domestic NdFeB magnet value chain. Alloy and especially metal production are currently anticipated to be weak links in the future U.S. NdFeB value chain. Based on the Department's survey of the U.S. NdFeB magnet industry, alloy and metal production facilities are also, on average, less expensive than domestic mining or magnet facilities. DoD DPA funding for alloy and metal facilities would be an efficient use of resources to strengthen the nascent NdFeB magnet value chain.

Encourage the Use of Export-Import Bank Financing

Eligible U.S. NdFeB magnet industry participants, including NdFeB magnet manufacturers and producers at upstream and downstream steps in the value chain, should be encouraged to apply for loans from the Export-Import Bank of the United States (EXIM). EXIM financing is another mechanism to help ease the financial constraints faced by the nascent U.S. NdFeB magnet industry. EXIM has two initiatives that are particularly relevant for the U.S. NdFeB magnet industry: the Make More in America Initiative and the China and Transformational Exports Program (CTEP).[376] [377] The Make More in America Initiative extends EXIM's existing medium- and long-term loans and loan guarantees to domestic manufacturers that export a sufficient percentage of production (15 percent or 25 percent depending on firm characteristics), scaled by jobs created. Importantly, export suppliers are also eligible. U.S. NdFeB magnet industry participants who meet export thresholds directly or because of their customer relationships, and are facing financing gaps, should be encouraged to apply for EXIM loans and loan guarantees under this initiative.

CTEP is meant to help U.S. exporters facing competition from China and ensure that the United States leads in ten transformational export areas, including renewable energy, energy storage, and energy efficiency. It is highly probable that U.S. NdFeB magnet industry participants that seek to enter export markets will face considerable competition from Chinese firms, given that China is the global leader in the NdFeB magnet value chain and Chinese magnets are less expensive than their non-Chinese counterparts because of favorable tax rebates and subsidies, among other factors. NdFeB magnet industry participants should also be encouraged to apply for EXIM financing under CTEP.

Provide Additional Support for Domestic Manufacturing
As directed by the Bipartisan Infrastructure Law, the Department of Energy has allocated nearly $3 billion to boost domestic production of technologies critical to clean energy of the future, including electric vehicles. Although much of this funding is directed at electric vehicle battery-related technologies, a portion of it could be devoted to funding domestic NdFeB magnet production, as these are critical to clean energy and national security.[378] For example, $140 million is earmarked for the design, construction, and build-out of a facility to demonstrate the

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[376] On the Make More in America Initiative, *see* "Make More in America Initiative," Export-Import Bank of the United States, n.d., https://www.exim.gov/about/special-initiatives/make-more-in-america-initiative.
[377] On the China and Transformational Exports Program, *see* "China and Transformational Exports Program," Export-Import Bank of the United States, n.d., https://www.exim.gov/about/special-initiatives/ctep.
[378] "Biden Administration, DOE to Invest $3 Billion to Strengthen U.S. Supply Chain for Advanced Batteries for Vehicles and Energy Storage," Department of Energy, February 11, 2022, https://www.energy.gov/articles/biden-administration-doe-invest-3-billion-strengthen-us-supply-chain-advanced-batteries.

commercial feasibility of a full-scale integrated rare earth element extraction and separation facility and refinery. The facility will use recycled feedstock derived from acid mine draining, mine waste, or other deleterious material to separate rare earths into oxides and refine oxides into metals. Building domestic capacity in this phase of the supply chain would support both electric vehicle battery and NdFeB magnet production.

In addition to these existing funding sources, the Department recommends that the Administration support legislative action to develop resilient supply chains through the allocation of additional funding, such as the Supply Chain Resilience Program. Additional funding from such programs should support investment in domestic manufacturing in all steps of the NdFeB magnet value chain.

Defense Priorities and Allocation System
The investigation into NdFeB magnets focuses foremost on the national security. Under Title I of the Defense Production Act (DPA), the President is authorized to require preferential acceptance and performance of contracts or orders (other than contracts of employment) supporting certain approved national defense and energy programs.[379] The Department is delegated authority, through Executive Order 13603, to implement these authorities for industrial resources, which it does through the Defense Priorities and Allocation System (DPAS) regulation. The Department has delegated specific priority rating authority with respect to industrial resources to DoD, DoE, DHS, and the General Services Administration (GSA). The U.S. Government should prioritize contracts for DoD programs while considering the extensive use of NdFeB magnets in U.S. critical industry to minimize "disruption to normal commercial activities" and "provide an operating system to support rapid industrial response in a national emergency."[380]

Access to neodymium and NdFeB magnets is critical to the industrial base as a highly customizable component with a variety of uses. DoD, DoE, and DHS should use or continue to use their delegated authority under the DPAS to place priority ratings on contracts for programs related to or containing NdFeB magnets and magnet components. DPAS use ensures that approved national defense programs receive the appropriate priority in the marketplace. DPAS authorities could be particularly useful in ensuring that U.S. NdFeB magnet industry manufacturers are able to acquire critical equipment in a timely fashion. Across the industry, potential domestic producers face average lead times of around eight months for equipment, and for some market segments this increases to ten months for critical equipment. The Department's survey of the U.S. NdFeB magnet industry indicated the United States is the top source for equipment. DPAS could therefore be successfully deployed to shorten lead times and hasten the development of the U.S. NdFeB magnet industry. In addition, once sufficient domestic sources of feedstock are available, employing DPAS authorities could enhance the timeliness and stability of supply and increase the ability of U.S. NdFeB magnet firms to maintain production.

Export Controls
The Department recommends the Administration consider restrictions on exports of materials relevant to the NdFeB magnet value chain under the International Emergency Economic Powers Act (IEEPA). Export controls could address market distortions in the NdFeB magnet value chain

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[379] The DPA's definition of "national defense" includes military, energy, homeland security, emergency preparedness, critical infrastructure and restoration, and military and critical infrastructure assistance to foreign nations. *See* e.g., "Defense Production Act Program Definitions," FEMA, n.d., https://www.fema.gov/disaster/defense-production-act/dpa-definitions.
[380] "Defense Priorities and Allocation System," Department of Defense, n.d., https://www.dcma.mil/DPAS/.

that create substantial difficulties acquiring or face inflated prices for feedstocks from domestic sources due to competition with foreign consumers. [TEXT REDACTED].[381] [TEXT REDACTED]. The economic implications of export controls on the value chain should be analyzed to determine their efficacy while considering their impact on U.S. allies.

National Defense Stockpile

The Strategic and Critical Minerals Stockpiling Act (50 U.S.C.§ 98 et seq.), as amended, provides for the acquisition and retention of strategic and critical minerals stocks to decrease and preclude U.S. dependence on foreign sources or single points of failure for supplies during national emergencies.[382] The Defense Logistics Agency (DLA) Strategic Materials oversees the National Defense Stockpile. In Fiscal Year 2023, DLA announced potential acquisitions of one hundred metric tons of rare earth magnet block, 600 tons of neodymium, and 70 tons of praseodymium, potential conversions of 12 tons of rare earth elements, and potential recovery from government sources of ten tons of rare earths.[383] [384] [385] These potential acquisitions are part of the Annual Materials Plan, which is an unconstrained budget estimate that assumes that Congressional authorization and funding are available. Actual acquisitions may be lower. In DLA's view, the availability of rare earth element ore is not a problem, between MP Materials, Chemours, and Lynas Rare Earths. Rather, the processing stages (oxide to separation to alloying) create production vulnerabilities. DLA has not announced the purchase of specific magnet grades. [TEXT REDACTED].[386] Although this stockpile is a welcome corrective to current supply chain vulnerabilities, the proposed quantities are small in relation to essential civilian and overall U.S. demand.[387] A disruption of the NdFeB magnet supply chain could cause an essential civilian shortfall of more than ten times DoD's annual peacetime consumption.[388] Demand, including by critical infrastructure sectors, is only expected to grow. The Department

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381 [TEXT REDACTED].

382 "The Strategic and Critical Materials Stockpiling Act (50 U.S.C. § 98 et seq.): As amended through Public Law 115-232, the National Defense Authorization Act for Fiscal Year 2019," Defense Logistics Agency, n.d., https://www.dla.mil/Portals/104/Documents/Strategic%20Materials/The%20Strategic%20and%20Critical%20Materials%20Stock%20Piling%20Act%20Amended%20Thru%20FY2019.pdf?ver=2019-01-09-151703-093.

383 "National Defense Stockpile Market Impact Committee Request for Public Comments on the Potential Market Impact of the Proposed Fiscal Year 2023 Annual Materials Plan," Federal Register, September 9, 2021, https://www.federalregister.gov/documents/2021/09/09/2021-19415/national-defense-stockpile-market-impact-committee-request-for-public-comments-on-the-potential.

384 As previously mentioned, NdFeB magnets are shaped to meet product requirements. Stockpiling unshaped magnet block is prudent as it can be cut to meet specific end-use demands. However, each magnet block can only produce one grade of magnet, which requires the purchase of magnet blocks at multiple grades based on end-use demand. Stockpiling rare earth oxides may be preferable as they can be refined into metals, alloyed, and manufactured into magnets and obviate the need to consider magnet shape and grade requirements. That said, the United States currently does not possess the requisite downstream capacity to turn rare earth oxides into NdFeB magnets so any stockpile of rare earth oxides would need to be processed overseas until domestic capacity is established.

385 NdFeB magnets typically contain about 30 percent rare earths, with combined neodymium and praseodymium content ranging from 19 to 29.5 percent depending on magnet grade and the remaining rare earths percentage composed of dysprosium or terbium. Based on the potential acquisition of neodymium and praseodymium the proposed National Defense Stockpile could produce up to about 1,980 tons of NdFeB magnet, not accounting for dysprosium or terbium requirements or material losses in the production process, in addition to the one hundred tons of rare earth magnet block.

386 Meeting between the Defense Logistics Agency and the Department of Commerce, (Virtual Meeting, November 23, 2021).

387 At a minimum, 2020 automobile sector demand was 3,300 tons of total U.S. demand of 16,100 tons. "Rare Earth Permanent Magnets: Supply Chain Deep Dive Report," Department of Energy, February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf.

388 "Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth: 100 Day Reviews Under Executive Order 14017," The White House, June 2021, https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf.

recommends that the Administration support further national stockpile purchases of NdFeB magnet block and constituent materials including neodymium, praseodymium, and dysprosium. The Department also suggests that the Administration explore whether to include a commercial buffer for select essential civilian and critical infrastructure sectors, which could strengthen supply chain resiliency in the event of disruptions caused by non-market forces.

[TEXT REDACTED]. DoD has requested $253 million in new appropriations for the National Defense Stockpile Transaction Fund in the President's Budget Request for Fiscal Year 2023. These funds build towards the $1 billion funding goal established by the June 2021 White House Report "*Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth: 100 Day Reviews under Executive Order 14017*."[389]

9.4.3 Bolster Domestic Demand

Cooperation and Information Sharing Between Producers and Consumers

The Department recommends that the Administration establish a forum under a lead U.S. Government agency to encourage information exchange and cooperation between emerging NdFeB magnet producers throughout the supply chain and NdFeB magnet end-users. As previously discussed, ensuring consistent domestic commercial demand is critical to the development of a U.S. NdFeB magnet industry. Industry stakeholders have cited uncertainty over both potential sources of domestic supply and consistent demand for domestic magnets as risks to the emerging U.S. NdFeB magnet value chain. This forum would provide additional assurance of domestic supply and demand, for example by promoting private sector offtake agreements using DPA Title VII. Japan's use of JOGMEC to establish definitive offtake agreements between overseas producers and Japanese consumers is a successful model the U.S. Government could emulate.[390] [391] Ongoing private sector efforts such as the recent agreements between General Motors and MP Materials and Vacuumschmelze are encouraging, but the U.S. Government should facilitate further cooperation.

This forum could also provide a platform to resolve other issues relevant to the NdFeB magnet industry. For example, industry participants could discuss whether developing a market in futures and derivatives based on neodymium or other rare earths could increase price transparency and reduce price volatility or provide additional access to capital markets that could be used to finance capital-intensive projects. The Chinese rare earths industry is already considering such a marketplace.[392] [TEXT REDACTED].[393]

Recycling and Reprocessing

The Department recommends that the Administration take legislative action to establish regulations and, working in collaborative with the private sector, voluntary consensus standards

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[389] Ibid.

[390] For an example, *see* "Sojitz and JOGMEC enter into Definitive Agreements with Lynas Including Availability Agreement to secure supply of Rare Earths products to Japanese Market," Japan Oils, Gas, and Metals National Corporation, March 30, 2011, https://www.jogmec.go.jp/english/news/release/release0069.html.

[391] JOGMEC's offtake agreement with Lynas Rare Earths enabled Lynas Rare Earths to survive a slump in rare earth element prices in the mid-2010s. JOGMEC-style actions and definitive offtakes more generally could be mechanisms to counteract price volatility in the rare earths market. Sonali Paul, "Japanese shore up cash-strapped rare earths miner Lynas," Reuters, March 13, 2015, https://finance.yahoo.com/news/japanese-shore-cash-strapped-rare-085926334.html.

[392] "China's SHFE speeds up RE futures research," Argus Media, October 21, 2019, https://www.argusmedia.com/en/news/1999255-chinas-shfe-speeds-up-re-futures-research.

[393] *See* Appendix F, "U.S. NdFeB Magnet Industry: Company Profiles."

to promote the recovery, recycling, and reuse of NdFeB magnets. In particular, labelling requirements for end-of-life products would ensure recyclers know NdFeB magnet specifications. Uncertainty over magnet specifications is a significant barrier to recycling, so labelling would facilitate recycling.

The Department also recommends that the Administration leverage existing programs and assets to increase the demand for recycling. DLA runs a Strategic Material Recovery and Reuse Program, which allows the recovery of strategic and critical materials from excess materials made available by other Federal agencies.[394] Through this program, DLA mitigated germanium shortfalls and recovered alloys from turbine engines.[395] DLA could potentially recover rare earth magnets from hard disk drives under this authority from the more than 4,000 U.S. Government-owned data centers and thereby generate a source of recyclable end of life material for recycling firms.[396] Leveraging U.S. Government-owned data centers would also give federal authorities an opportunity to lead private industry in secure destruction of the devices containing NdFeB magnets without damaging the magnets. As noted above, private entities often shred their data devices; they may be more willing to follow secure destruction practices identified by the U.S. Government. In addition, Federal agencies could direct any Federally-owned end-of-life electric vehicles or wind turbines using NdFeB magnets to recycle contained magnets.

Finally, the Department recommends that the Administration evaluate whether removing and processing tailings sites, for example of heavy mineral sands and coal tailings, could ameliorate environmental concerns at site locations.[397] [398] If removing heavy mineral sands and coal tailings would improve environmental indicators at site locations, the Environmental Protection Agency should assess whether environmental cleanup funds such as its Superfund program could be used to repurpose these sites. Monazite, produced as a byproduct of heavy mineral sands operations and traditionally considered a waste material, and coal tailings are potential rare earth element feedstocks. As a result, removing and processing tailing sites could provide an additional source of rare earths and increase the resilience of the U.S. NdFeB magnet value chain.

Domestic Content Requirements

In Executive Order 14057, "Catalyzing Clean Energy Industries and Jobs through Federal Sustainability", the Biden Administration mandated that all federal agencies buy electric vehicles (in total about 600,000 car and trucks) by 2035 and that all 300,000 federal buildings be powered by wind, solar, or nuclear energy by 2030.[399] In addition, greatly expanded offshore wind energy

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[394] "Strategic Material Recovery and Reuse Program," Defense Logistics Agency Strategic Materials, n.d., https://www.dla.mil/HQ/Acquisition/StrategicMaterials/RRSMRP/.
[395] Ibid.
[396] "Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth: 100 Day Reviews Under Executive Order 14017," The White House, June 2021, https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf.
[397] Heavy mineral sands operations produce monazite as a byproduct. Monazite was historically considered a waste material due to its radioactive content. As a result, monazite was blended into sand and reburied. Removing and processing monazite could therefore be conceptualized as reusing existing waste material. Meeting between Energy Fuels and the Department of Commerce, (Virtual Meeting, March 1, 2022).
[398] Multiple private and public sector actors are actively seeking to clean up coal mine byproduct waste while extracting rare earth elements. *See* Austyn Gaffney and Dane Rhys, "In coal country, a new chance to clean up a toxic legacy," Washington Post, May 19, 2022, https://www.washingtonpost.com/climate-solutions/2022/05/19/coal-mining-waste-recycling/.
[399] "Fact Sheet: President Biden Signs Executive Order Catalyzing America's Clean Energy Economy Through Federal Sustainability," The White House, December 8, 2021, https://www.whitehouse.gov/briefing-

is a major aspect of the Administration's efforts to accelerate the United States' clean energy economy and fight climate change. To support a vibrant and resilient green technology supply chain, federal procurement rules should specify that, to the extent possible, the electric vehicles purchased use domestically produced NdFeB magnets, and that the wind turbines supplying energy to federal facilities use domestically produced NdFeB magnets (for those using NdFeB magnets). The Department of Interior is sponsoring an offshore wind lease sale that includes lease provisions to promote the use of domestic materials.[400] These provisions should cover NdFeB magnets. In addition, electric vehicles and wind turbines might be procured by state or local governments or with state or local funding, and such content requirements could expand to these purchases. Domestic content requirements could mirror those of defense applications, which already have non-Chinese content requirements, and thereby include U.S. allies. Ensuring that requirements are structured to include magnets produced by U.S. allies is important to guarantee U.S. Government demand is adequately supported. To minimize disruption to U.S. procurement, content requirements can be phased-in and waived if insufficient quantities of eligible NdFeB magnets are available.

Consumer Rebates
Consumer rebates are another mechanism to incentivize the domestic production of NdFeB magnets. The Department recommends that the Administration develop and implement a tax rebate for consumers who purchase electric vehicles that are certified to contain U.S. or U.S. ally origin content. This rebate would help compensate automobile manufacturers for the increased cost of using domestic or ally produced NdFeB magnets. Such a rebate need not be limited to NdFeB magnets but could include U.S. or U.S. ally origin content batteries as well.

9.4.4 Support Medium- to Long-term Industry Development and Resiliency
Research into Reducing the Use of Rare Earth Elements

The Department recommends that the Administration continue to fund research that seeks to reduce rare earth element content, and especially heavy rare earth element content, in NdFeB magnets, develop NdFeB magnet substitutes, and avoid the use of magnets, including NdFeB magnets, in end-use products. This includes support for research on MQ3 magnets, which could reduce or eliminate heavy rare earth contents, more efficient NdFeB magnets, potential non-NdFeB magnets such as iron-nitride magnets, and assemblies that obviate the need for NdFeB magnets in applications such as electric vehicle motors and wind turbine generators.[401] Reducing rare earth element content would help alleviate projected rare earths shortages and increase supply chain resiliency by reducing dependence on China.

Human Capital Development
The Department recommends that the Administration use applicable programs to support the development of human capital as required by the nascent U.S. NdFeB magnet industry. The collapse of the U.S. NdFeB magnet industry in the 1990s hollowed out industry-specific

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room/statements-releases/2021/12/08/fact-sheet-president-biden-signs-executive-order-catalyzing-americas-clean-energy-economy-through-federal-sustainability/.
[400] "Fact Sheet: Biden Administration Jumpstarts Offshore Wind Energy Projects to Create Jobs," The White House, March 29, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/29/fact-sheet-biden-administration-jumpstarts-offshore-wind-energy-projects-to-create-jobs/.
[401] [TEXT REDACTED]. Meeting between Turntide Technologies and the Department of Commerce, (Virtual Meeting, February 17, 2022).

knowledge and skills, such that the United States' stock of NdFeB magnet-related human capital is limited. Current and potential domestic producers indicated that finding qualified and experienced manufacturing engineers and scientists is an important constraint on their operations. Some firms also indicated that finding qualified and experienced production line workers is an issue. The U.S. Government, state governments, and local authorities should work with industry, labor, and educational institutions to develop skills relevant to NdFeB magnet production by creating and expanding training programs and scholarships. For example, the Department of Labor's Employment and Training Administration funding opportunities, such asthe Strengthening Community Colleges Training Grant, could be used to establish and enhance educational programs that teach NdFeB magnet-related skills.[402]

In addition, eligible entities should be encouraged to apply for the Economic Development Administration's Public Works and Economic Adjustment Assistance programs.[403] For example, higher education institutions or local governments in distressed communities (including coal communities) could apply for grants to develop and strengthen training facilities related to NdFeB magnet manufacturing, such as materials science.[404] Supporting the development of human capital related to the NdFeB magnet value chain would help grow a robust domestic NdFeB magnet industry and by extension enhance the resiliency of end-use product supply chains, including electric vehicles and offshore wind turbines.

9.4.5 Continue to Monitor the NdFeB Magnet Value Chain

The Department recommends that the Administration continue to monitor the NdFeB magnet value chain to ensure that U.S. and ally firms are not adversely impacted by non-market factors or unfair trade actions, such as intellectual property violations or dumping. As previously discussed, the U.S. NdFeB magnet industry disappeared in the 1990s and early 2000s in part because of Chinese policies such as tax rebates and subsidies as well as intellectual property infringement. To ensure that the nascent U.S. NdFeB magnet industry survives, the U.S. Government should remain cognizant of the health of the industry and the effects of Chinese competition. The Department and the Supply Chain Trade Task Force should periodically assess the health of the U.S. and global NdFeB magnet value chain to determine whether additional actions should be undertaken to counterbalance non-market factors or unfair trade practices.

Thea D. Rozman Kendler,

Assistant Secretary for Export Administration.

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[402] For current Employment and Training Administration funding opportunities, *see* "Funding Opportunities," U.S. Department of Labor, n.d., https://www.dol.gov/agencies/eta/grants/apply/find-opportunities.
[403] *See* "PWEAA2020 FY 2020 EDA Public Works and Economic Adjustment Assistance Programs Including CARES Act Funding," Grants.gov, last modified April 1, 2022, https://www.grants.gov/web/grants/view-opportunity.html?oppId=321695.
[404] Some planned NdFeB magnet industry participants are located in areas that may qualify as distressed communities, while others are situated in places that could qualify as coal communities, such as Kentucky and Tennessee. Training facilities in these areas could be particularly useful for developing a local pipeline for talent.